KT

Applications of Aerospace Technology in the Public Interest: Pollution Measurement

(NASA-CR-137233) APPLICATIONS OF AEROSPACE TECHNOLOGY IN THE PUBLIC INTEREST: POLLUTION MEASUREMENT (Denver Research Inst.) 62 p HC $6.25 CSCL 13B

N74-19234

G3/20 Unclas 16933

University of Denver • Denver Research Institute

APPLICATIONS OF AEROSPACE TECHNOLOGY IN THE PUBLIC INTEREST:

POLLUTION MEASUREMENT

Prepared for

The Technology Utilization Office
(Code KT)
National Aeronautics and Space Administration

Contract NASW-2362

Prepared by

Conrad F. Heins
F. Douglas Johnson
Industrial Economics Division
Denver Research Institute
University of Denver

February 1974

TABLE OF CONTENTS

INTRODUCTION

Because of unique mission requirements, the National Aeronautics and Space Administration (NASA) has contributed in important ways to the quest for an improved environment. The life-support mission of NASA has the same broad objectives as the national imperatives toward environmental restoration: pure air, clean water and reuse of resources. The major difference is the vast scale of the earth environment, compared to the very small scale of spacecraft. It is not surprising, then, to find that instruments which were developed to monitor spacecraft environments are now being adapted to monitor air and water pollution.

Likewise, the space program has made possible entirely new ways of viewing the earth—views more comprehensive than man has ever known. The development of this capability over the last ten years has given birth to a new field of technology, that of remote sensing from space. While the impact of remote sensing is only beginning to be realized, its promises have grown rapidly as scientists and engineers developed the new tools needed for a better understanding of the earth's resources and environment.

In recent years, NASA-sponsored efforts have accounted for about 20 percent of all environmentally related federal R&D expenditures. These expenditures have had a direct bearing on many aspects of the nation's environmental quality, particularly as the NASA effort addressed the question, "What is the present condition of the environment?"

This study of selected NASA contributions to the improvement of pollution measurement examines the pervasiveness and complexity of the economic, political, and social issues in the environmental field (Section I); provides a perspective on the relationship between the conduct of aerospace R&D and specific improvements in on site air pollution monitoring equipment now in use (Section II); describes the basic relationship between the development of satellite-based monitoring systems and their influence on long-term progress in improving environmental quality (Section III); and, finally, comments on how both instrumentation and satellite remote sensing are contributing to an improved environment (Section IV). An attachment has been included to elaborate, through examples, specific gains that have been made in applying aerospace R&D to environmental problem-solving.

SECTION I: AN OVERVIEW OF THE ENVIRONMENTAL MEASUREMENT FIELD

When the first brushfires of discontent with the quality of the environment were erupting in the United States, few could have forseen the intensity of public protest that was to mark the 1970's. Agitation with the effects of air and water pollution precipitated the need for legislative action and strong federal control of the nation's resource base.

In response to this need, the U. S. Environmental Protection Agency (EPA) was organized on December 2, 1970 to administer a widespread program for pollution control and abatement. Shortly thereafter, EPA and others predicted that, in 1971 dollars, total national annualized costs of pollution control–public and private–would rise from $10.4 billion in 1970 to $33.3 billion in 1980 (Council on Environmental Quality, 1972). The same estimates put total spending for pollution control during the decade at $287.1 billion (see Table 1-1). While the amount is very large in absolute terms, it still represents only 2.2 percent of the estimated total Gross National Product for the period of 1970 to 1980.

TABLE 1-1. TOTAL POLLUTION CONTROL EXPENDITURES, 1970-1980 (IN BILLIONS OF 1971 DOLLARS)*

POLLUTANT/MEDIUM	ANNUAL COST 1970	ANNUAL COST 1980	TOTAL CUMULATIVE REQUIREMENTS 1971-1980
Air	$ 0.8	$14.7	$106.5
Water	3.6	8.0	87.3
Solid Waste	6.0	9.7	86.1
Other	0.0	0.9	7.2
Totals	$10.4	$33.3	$287.1

*Source: Council on Environmental Quality, 1972.

In terms of current expenditures, U. S. business planned to spend $6.22 billion in 1973 alone to control air and water pollution. Total pollution control spending in 1973 will thus account for 5.9 percent of industry's planned capital investment, up from 5.1 percent the previous year. In addition, industrial research and development on environmental problems is expected to cost some $1.53 billion in 1973, 4 percent more than in 1972 (McGraw-Hill Publications Company, 1973).

Such efforts are creating a brisk and growing market for the instruments and related equipment required to measure the condition of the environment–to determine, that is, whether the money being spent is buying the desired results. The U. S. market for air pollution test and measuring systems has been put at $12 million in 1970 and $120 million in 1980 (Predicasts, Incorporated, 1973). The same source estimates sales of water pollution monitoring equipment at $875 million in 1970 and $1.2 billion in 1980.

Expenditures like these reinforce a point that has been clear for a long time—a clean environment does not come cheaply. Besides the costs of monitoring and controlling current pollution conditions, the U. S. economy has suffered measurable losses in capital and productivity. For example, the annual cost of air pollution damage to the American people must also take into account:

- Additional costs for health care and impairment of human resources;
- Reduction in residential property values;
- Degradation of materials; and
- Damage to vegetation and agricultural activity.

Legislative Background

The federal government entered the air pollution picture with the Air Pollution Act of 1955, which authorized the first federally funded research on air pollution. Later, the Motor Vehicle Pollution Control Act of 1965 established the authority to set emission standards for automobiles. The government's current programs in air pollution, however, largely grew out of the Air Quality Act of 1967 and the Clean Air Act of 1970 (U. S. Environmental Protection Agency, 1972).

The Clean Air Act of 1970 was the first to require national, uniform air quality standards based on geographic regions. The standards are given in terms of concentrations of specific pollutants and are of two types:

- *Primary standards*—which define the level of air quality necessary to preserve human health; and
- *Secondary standards*—which are designed to promote the public welfare and prevent damage to animals, plant life and property.

In April 1971, EPA promulgated primary and secondary national standards for six major air pollutants: sulfur oxides, particulate matter, carbon monoxide, hydrocarbons, photochemicals and nitrogen oxides.

Under the Clean Air Act of 1970, EPA also divided the country into some 250 Air Quality Control Regions (AQCR's). Since air pollutants disregard political boundaries, the AQCR's are interstate regions based, where feasible, on jurisdictional boundaries, as well as on urban-industrial complexes and other factors selected to facilitate the implementation of the air quality standards. State governments and other jurisdictions had to draw up implementation plans designed to meet primary air quality standards in each AQCR by 1975 and to meet the secondary standards on a more flexible basis.

Besides the state implementation plans and related mechanisms, the law gives the federal government special authority in certain matters that are inherently interstate or that involve a severe threat to human health. These include control of new stationary sources of air pollution, hazardous air pollutants, motor vehicle emissions, fuels and fuel additives, and aircraft emissions.

The government effort to control water pollution began with the Federal Water Pollution Control Act of 1948, followed by the Water Pollution Control Act Amendments of 1956 and the Water Quality Act of 1965. The latter provided for water quality standards enforceable by the federal and state

governments, and it became the basis for interstate water quality standards. Government authority was further extended by the Clean Water Restoration Act of 1966 and the Water Quality Improvement Act of 1970. By that time water pollution legislation had grown much too complex, and, also, it was by no means clear that the nation's waters were much cleaner than they had been 20 years earlier. As a result, the Water Pollution Control Act Amendments of 1972 were passed.

The Act of 1972 shifts the focus of water pollution control from water quality standards to effluent limitations. That is, instead of regulating the amount of pollutants in a body of water, the law seeks to regulate the amounts being discharged from specific point sources. In effect, the Act envisions two national goals: one is to achieve, by July 1, 1983, a level of water quality that protects fish, shellfish, wildlife, and recreation; the second is to eliminate the discharge of all pollutants into the navigable waters of the U. S. by 1985 ("zero-discharge" provision). The Act allows no discharge without a discharge permit.

In addition, the Administrator of EPA must specify the best technology for preventing and reducing water pollution. Industrial dischargers will be required, by July 1, 1983, to meet the standards achievable with such technology. Although zero discharge is a goal and not a requirement of the law, the administrator can direct industrial dischargers to comply, by July 1, 1983, where he finds that it is economically and technologically feasible.

As with air, states must submit water quality standards and implementation plans for EPA approval. The state standards classify water by its intended use: recreation; fish and wildlife propagation; public water supply, and industrial and agricultural uses. The implementation plans are designed to maintain the water quality appropriate to the use. Starting in 1975, the states must report annually to Congress and EPA an inventory of all point sources of discharge, an assessment of current and projected water quality, and proposed controls for nonpoint sources of discharge.

The EPA has a range of water-related responsibilities in addition to those outlined above. These other duties include the establishment of performance standards for new discharge sources and marine sanitation devices; the establishment of standards for drinking water quality and toxic pollutant effluent limitations; and the control of thermal discharges and ocean dumping.

Federal R&D for the Environment

Most of the economically feasible technology required to achieve the legislative standards and goals for the near future does not exist. This fact has led to a broad-based R&D effort by more than a dozen federal agencies, as well as by hundreds of nongovernmental organizations. These efforts are not autonomous, however. At a hearing before the Senate Committee on Aeronautical and Space Sciences on March 15, 1973, Dr. Stanley Greenfield of EPA's Research and Monitoring Division stated that:

> The movement of pollutants horizontally and vertically through the environment knows no political boundaries. As a result, the monitoring of our Nation's environmental quality must be a cooperative effort involving all levels of government.

Among the numerous federal agencies involved in efforts to improve environmental quality, the National Aeronautics and Space Administration is a major participant in terms of environmental research and development activities. The relative importance of NASA environmental R&D with respect to aggregate federal research expenditures is indicated in Table 1-2. The federal agencies listed in this table spent a total of $698 million in 1971, and an estimated $834 million in 1972 and $956 million in 1973,

for environmental R&D–with NASA and EPA leading the way. While EPA allocated its total expenditures for pollution control and abatement, NASA's outlays were largely spent on understanding, describing, and predicting pollution effects.

TABLE 1-2. OUTLAYS FOR RESEARCH AND DEVELOPMENT, BY FEDERAL AGENCY – 1971-1973*

AGENCY	OUTLAYS IN MILLIONS OF DOLLARS		
	1971 (ACTUAL)	1972 (ESTIMATE)	1973 (ESTIMATE)
Environmental Protection Agency	$109	$157	$174
National Aeronautics and Space Administration	181	171	163
Department of the Interior	105	125	159
Department of Commerce	54	86	114
Atomic Energy Commission	89	92	102
Department of Defense	64	76	83
Department of Agriculture	67	75	76
Department of Transportation	21	40	67
Other**	8	12	18
Totals	$698	$834	$956

*Source: Talley, 1973.

**Tennessee Valley Authority, Smithsonian, Post Office, Corps of Engineers, Department of State, General Services Administration, Housing and Urban Development, and Appalachian Regional Commission.

The breadth and depth of the government's concern for the environment is evident from the categories utilized by Syracuse University Research Corporation in a study of environmental research being conducted in federal laboratories (see Table 1-3). The Syracuse study covered 170 federal laboratories, seeking information on each laboratory's major mission and a brief description of current in-house environmental resear[illegible] (Teich, 1971).

TABLE 1-3. SPAN OF FEDERAL R&D ACTIVITY*

ENVIRONMENTAL CATEGORIES	ENVIRONMENTAL RESEARCH PROGRAMS
Air Quality	• Measuring and monitoring pollutants; studies of their treatment and fate • Prevention and control of pollution • Evaluation of effects of pollution
Water Quality	• Development of pollution control technology (agricultural, industrial, mining, municipal and other sources; including salinity and thermal addition) • Water quality monitoring and improvement (including characterization and quantification of sources, kinds, amounts, prevention, control, effects, reclamation, and fate of pollutants; reversal of eutrophication; improvement of effluent quality) • Methods of waste treatment and ultimate disposal • Water quality requirements research (establishment of standards, prediction of effects of new substances)
Land Quality	• Disposal of processing wastes (animal, forest and crop, heavy metals, industrial, mining) • Control of sediments, erosion, salinity, and plant nutrients • Disposal of urban solid wastes
Understanding, Describing, and Predicting the Environment	• Ecology and other environmental research (including studies of forestry, fish, and wildlife ecology) • Studies of atmospheric and oceanic phenomena (including weather prediction and modification) • Surveys of natural resources and the physical environment • Impact of the environment on man (including environmentally related occupational health)
Protecting and Enhancing the Environment	• Studies of fish and wildlife resources, rural and wild land environments, urban and suburban environments • Water resources (including water supply yield and quality)
Special Studies	• Pest control research (alternatives to use of pesticides, etc.) • Noise research (effects, control, reduction) • Radiation (ionizing and nonionizing–transport and fate, protection, prevention and control, evaluation of effects)

*Source: Teich, 1971.

Environmental Monitoring

The ability to detect and measure contaminants is inseparable from an environmental effort that is tied to standards defined in terms of concentrations of specific pollutants in air or water. The broad goals of environmental monitoring are:

- To measure the condition of the environment;
- To detect trends;
- To evaluate compliance with air and water quality standards; and
- To follow the movement of contaminants among air, water, soil and life forms.

The environment is presently monitored by federal, state, and local agencies through instrumentation networks as well as by special studies designed to obtain data that the networks do not provide. The networks are comprised of fixed stations where samples are taken periodically or where instruments monitor certain pollutants continuously. By 1972, more than 8,000 long-term monitoring stations were operating (see Table 1-4), and special-purpose samples could be taken at some 30,000 sites.

TABLE 1-4. ENVIRONMENTAL MONITORING STATIONS, 1972*

MEDIA	NO. OF STATIONS		
	EPA	STATE AND LOCAL	TOTAL
Air–Continuous[a]	10	90	100
–Intermittent[b]	300	2100	2400
Water–Continuous	60	240	300
–Intermittent	840	2000	2840
Soil–Intermittent	3000	NA	3000
Totals	4210	4430	8640

[a]Continuous monitoring stations–automated stations with instrumentation for four or more parameters.

[b]Intermittent monitoring stations–manual, intermittent samplers or continuous instrumentation for less than four parameters.

*Source: Morgan, 1973.

These monitoring operations generate immense amounts of data. To make such information accessible, EPA uses computerized systems: the National Aerometric Data Information System (NADIS); the National Emissions Data System (MEDS); the Water Data Storage and Retrieval System (STORET); and the National Water Data Exchange (NWDE).

Technological deficiencies of present monitoring systems. Environmental laws in the U. S. have clearly outrun the pertinent technology; one can argue plausibly that little would have happened otherwise. Ironically, the technological gap is especially noticeable in measurement, the most crucial parameter of the legal system. In 1969 and again in 1971, the American Chemical Society remarked on "the inadequacy of many analytical chemical methods used to monitor, control, and study the environment and the related phenomena," and "the lack of data adequate to allow us to define normal trends in the concentrations of contaminants in the environment, to define deviations from normal trends, and to design valid models for subsystems of the environment" (American Chemical Society, 1969 and 1971).

More specifically, the methods used to monitor water quality today do not differ markedly from those used at the turn of the century; most scientific progress has been toward improving laboratory techniques. Nearly all of the air monitoring instruments installed up to 1970 used analytical techniques 10 to 15 years old. The pressures of recent legislation are pushing the serious deficits in measurement capability into public view where they are beginning slowly to draw long-warranted attention (see Section II on "NASA Contributions to On Site Instrumentation for Air Pollution Monitoring").

Rapid solutions, however, are not available. Part of the problem is that instrumentation required to provide the needed measurements is often pushing the state-of-the-art. Another difficulty lies in the fact that measurements are required even though the complete reliability of the measuring technique is still being determined.

Air analyses. After the passage of the Clean Air Act of 1970, the concern over problems that can flow from a breakdown in measurement methodology intensified, since this Act presumed the existence of sound analytical techniques. In 1971 the American Society for Testing and Materials (ASTM) launched Project Threshold to validate measurement methods for air contaminants and to provide a technical basis for resolving measurement problems.

ASTM is using the time-honored collaborative-test approach in which different operators in different laboratories apply the same analytical method to different parts of the same sample and then compare results. Such tests have rarely been made on air pollutant analyses of the EPA's six standard reference methods for air pollutants; in fact, only those for sulfur oxides and particulate matter have been tested collaboratively. One reason is that, until the late 1960's, no means was available for generating in standard samples the very low concentrations of contaminant gases common in ambient air. The device that was finally developed–the permeation tube–was instrumental in discrediting the original reference method for nitrogen dioxide. A second reason for the lack of collaborative testing is the cost and difficulty of dividing a cubic meter of air containing 100 milligrams of NO_2 into equivalent samples and delivering them unaltered to half a dozen laboratories. ASTM solved the latter problem by moving the laboratories to the sample instead of the other way around.

By May 1973, ASTM had validated six methods for measuring the quality of ambient air, including two for particulate matter and one each for sulfur dioxide and nitrogen dioxide. The Society was also conducting on site collaborative tests of source-emission methods, which will become increasingly important to the enforcement of air quality laws and regulations. In addition, Project Threshold conducted the first on site interlaboratory tests ever made to determine the reproducibility of stack-emission measurement methods (for particulate matter, collected residue, sulfur oxides, nitrogen oxides, and velocity of the stack gas).

Water analyses. The Water Pollution Control Act of 1972, with its emphasis on point sources, will necessarily lead to considerably expanded measurement of specific pollutants in waste discharges. A variety of analytical techniques is available, and, compared with the methods used for air, they have been tested relatively well for reliability, precision and accuracy.

Problems and inadequacies, however, still exist in the area of water measurement technology. Field equipment of proven reliability for monitoring a number of waste constituents must be developed. In addition, most water monitors were designed originally to monitor ambient waters, where contaminant concentrations tend to be relatively low, as opposed to effluent sources, where concentrations are higher. The analytical technique may be the same, but effluent analysis as a rule requires a less sensitive instrument better able to cope with interferences, corrosion and suspended solids. More instruments designed specifically for source monitoring are required instead of the commonly used dual-purpose equipment.

Organic pollutants in water have in the past been analyzed mainly by collective methods, such as biochemical oxygen demand, which do not detect individual compounds. Many such compounds, however, enter the environment regularly. Some of them may exert unusual effects in addition to depleting the oxygen in ambient water as they degrade biologically. As a result, EPA began upgrading its ability to identify specific organic chemicals in water. In December 1972 scientists at the EPA laboratory in Athens, Georgia were able to list some 250 organic contaminants that have been detected in ambient waters. They believe that the number potentially present lies between 10,000 and 100,000.

Future measurement needs. The EPA officials have pointed out a number of continuing and more general problem areas in environmental measurement (Morgan, 1973). Among these is the need to improve procedures for collecting and maintaining the integrity of samples, especially gaseous samples. Methods must be developed for determining pesticide contamination of air, water, soil, and tissue in comparable terms. A wider range of reference materials and standards is needed, such as the permeation tube now used to make standard samples of several gases.

Additional effort is also needed to refine the applications for advanced monitoring and remote sensing technologies. The latter, for example, has been demonstrated to be feasible for monitoring coastal oil spills and lake eutrophication. Remote sensing techniques developed by other government agencies are applicable to EPA's monitoring needs with minimum further development (see Section III on "Selected NASA Contributions to Environmental Measurement by Satellite Remote Sensing").

Environmental Models and Community Health

In order for monitored data to be effective, it must be used in a broad context that will link pollutant concentration to human effects. This is done with environmental models that relate pollutant dosage to effects on the quality of community health. For example, the health effects of sulphur dioxide are illustrated in Figure 1-1. The development of such models has been the subject of intensive research.

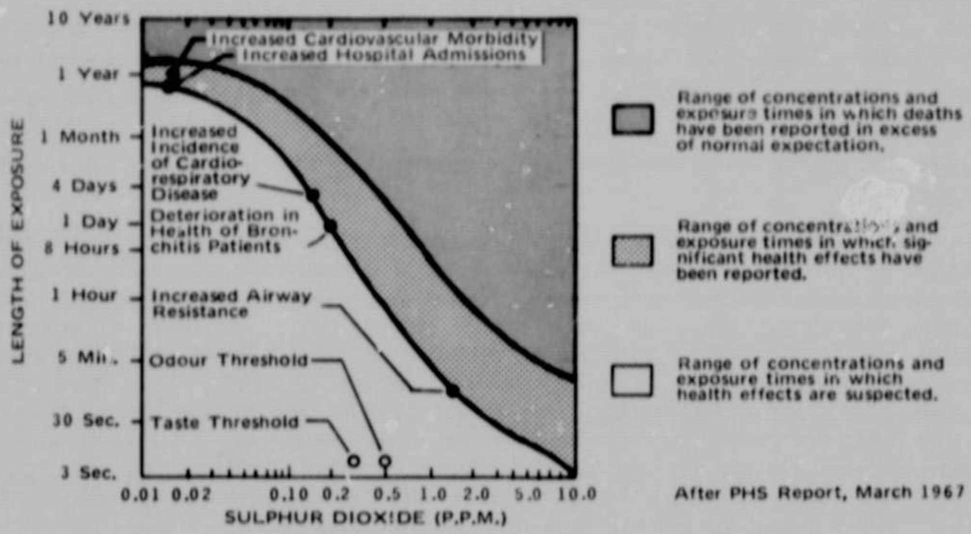


Figure 1-1. Health Effects of Sulphur Dioxide Pollution. [Source: Barringer, 1970.]

The New York State Department of Environmental Conservation and Department of Health have installed an automatic air and water monitoring system that is among the most advanced in the world. The new system, called the Empire State System, provides for the automatic electronic monitoring of environmental conditions in the state and for the rapid transmission of the monitored data to an on-line computer at the state's Health Department for processing, evaluating and reporting. As a result, Environmental Conservation officials are provided with almost instantaneous information on excessive levels of pollution so that appropriate measures can be taken.

Another program, administered by EPA, attempts to explore the complete pollution envelope of a single urban area in enough detail to allow the processes that determine the concentrations of air pollutants at various points to be described in a series of mathematical models. The program, known as the Regional Air Pollution Study (RAPS), will employ 25 air monitoring stations around St. Louis, Missouri to measure such parameters as pollutant concentrations, wind, temperature, humidity and solar radiation.

One complementary program to RAPS is an EPA epidemiological study which offers systematic, definitive correlations of health effects with long-term, low-level exposure to various pollutants. Since information of this kind is essential to sound environmental managment, EPA is working to obtain it through the Community Health and Environmental Surveillance System (CHESS). The approach employs standardized epidemiological studies designed to measure, simultaneously, selected indicators of environmental quality and human health in sets of communities that represent gradients of exposure to common air pollutants.

Conclusion

The national concern over environmental quality, so dramatically demonstrated on Earth Day, April 22, 1970, has resulted in the passage of new and comprehensive federal legislation. This legislation, such as the Clean Air Act of 1970, not only characterizes the national commitment to improving the environment but also establishes a legal imperative to deal with the problems of environmental pollution.

Since environmental legislation determines standards for pollution control in terms of concentrations of specific pollutants, the implementation of these standards is largely dependent upon the availability of instruments to detect and measure pollutants. The following statement presented at the Interagency Conference on the Environment, held in Livermore, California in October 1972, demonstrates the importance of developing the measurement techniques necessary for improving the environment:

> Monitoring is one of the keys to effective management of the quality of the environment. Changes in the environment, desirable or undesirable, natural or man-made, cannot be determined unless baselines have been established and systematic observations are made. Further, it is not possible at the present time to predict, with any certainty, the effects of various control measures that might be followed in the alleviation of the problem. Measurements of environmental quality are essential for determining needs, establishing priorities, and for evaluating the effectiveness of control and abatement programs. As noted by the President's Council on Environmental Quality in their second annual report, without valid environmental data the most important problems cannot be determined nor can the effectiveness and success of methods of attacking them be established. 'Monitoring is not a substitute for action. But in the long run, action without the knowledge provided by adequate monitoring is more likely to be ineffective' (Lawrence and Keafer, 1973).

Thus, the implied need for expanded measurement techniques is most useful as the background for the following discussion of NASA's role in pollution measurement.

SECTION II. NASA CONTRIBUTIONS TO ON SITE INSTRUMENTATION FOR AIR POLLUTION MONITORING

The Clean Air Act of 1970 forced the development of improved pollutant monitoring instruments that embody advanced measurement technology. One result of this developmental effort to provide reliable and accurate measurements of pollutant concentrations has been a shift from standard wet chemical techniques to advanced spectroscopic techniques.

A recent article in *Science* magazine by Environmental Protection Agency staff members discussed the characteristics and historical development of these two measurement techniques:

> Before 1970, requirements for the measurement of gaseous pollutants were largely met by the use of instruments which were automated versions of standard wet chemical procedures. Such instruments were complex and were characterized by high maintenance requirements and marginal sensitivity and specificity. Spectroscopic techniques, whether in emission or absorption, offer means for the direct and continuous detection of the pollutant in the gas phase. The absorption or emission characteristics can serve to identify a pollutant and to measure its ambient concentrations. Furthermore, spectroscopy offers means for the direct observation of pollutants at a point or over an extended path without the need for any intervening sampling apparatus . . . .
>
> Although the potential of spectroscopic techniques was recognized during the 1950's and early 1960's, the techniques and instrumentation had not advanced to the point that would make possible the design of simple, specific, and sensitive spectroscopic sensors. In more recent times, there has been a virtual renaissance in spectroscopic measurements of atmospheric pollutants. This revival of interest was instigated in part by the impending legislation and monitoring needs of the 1970's. Other major factors, however, have been the development of new spectroscopic techniques and the evolution of advanced optical components suitable for use in routine monitoring instruments (Hodgeson, 1973).

Spectroscopic instruments measure pollutant concentrations by analyzing the effect of pollutant molecules on electromagnetic radiation (ultraviolet, visible light, infrared and microwave). This is possible because all molecules can be identified by the combination of wavelengths at which they characteristically emit and absorb radiation. Sophisticated instrument technology, however, is required to design a unit that provides a reliable measurement for a specific molecule to the exclusion of all others. Spectroscopic units typically include optical components, electronic components such as detectors and amplifiers, and electrical processing components that analyze the signal to produce an indirect numerical measurement of the pollutant.

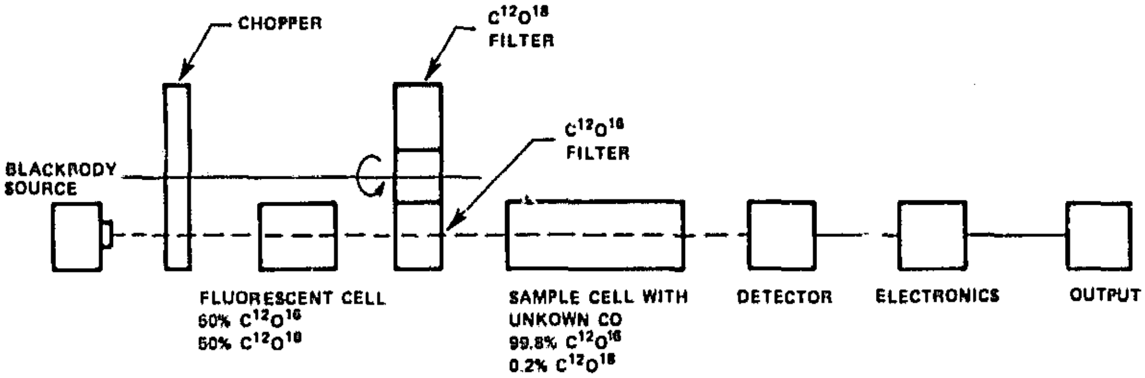
Advanced spectroscopic techniques and electronic components have been embodied in instruments originally developed by NASA for mission-oriented activities. In this section, three examples are described which illustrate how NASA-funded advances in spectroscopy have been used in the development of new air pollution monitoring instruments for carbon monoxide, auto emissions, and formaldehyde (a component of photochemical smog).

Dual Isotope Fluorescence Carbon Monoxide Analyzer

The EPA reference method for measuring carbon monoxide (CO) is nondispersive infrared (NDIR) spectroscopy. The typical NDIR analyzer has several important operational problems in normal air pollution monitoring applications. Since the unit does not distinguish (selectivity) between water vapor and CO, all water vapor in the sample must be removed by another device before measurement. In

addition, the standard unit has a diaphragm mechanism which is susceptible to external vibrations and not rugged enough for normal use in field operations. Maintenance problems occur with the sample chamber, where dirt and condensation will degrade the unit's accuracy, and with the electronic components, which are not stable in extended monitoring applications (Maugh, 1972).

A new principal of operation for NDIR–dual isotope fluorescence–was developed for the Skylab cabin CO analyzer to eliminate these problems and to increase sensitivity to 0.1 parts per million (ppm) (see Figure 2-1). Subsequent commercialization of this unit has redefined the state-of-the-art for NDIR carbon monoxide analyzers.



The dual isotope fluorescence NDIR contains a broadband infrared source that stimulates fluorescence in the two CO isotopes (CO^{16} and CO^{18}) in a sealed cell. The stimulated radiation is alternately filtered for the absorption band wavelengths of each isotope by a rotating chopper. This selectively chopped beam is transmitted through the sample chamber to a solid state photocell detector. Since the radiation wavelengths emitted by CO^{16} and CO^{18} are close to each other, the two beams are equally absorbed by water vapor or other interfering pollutants in the sample. On the other hand, 99.8 percent of the naturally occurring CO is in the form CO^{16}, so only the CO^{16} fluorescence is absorbed by CO in the sample, and the CO^{18} fluorescence passes through the sample as a reference beam. Hence, the photocell alternately receives the reference CO^{18} beam and the CO^{16} beam which has been reduced by an amount proportional to the concentration of CO in the sample. Electronic components then compare these two signals from the photocell to produce a numerical reading.

Figure 2-1. Dual Isotope Fluorescence Carbon Monoxide Monitor [Source: Becker, 1972.]

Gas samples do not have to be conditioned for the dual isotope unit because the effect of water vapor and other contaminants is eliminated by using one isotope to produce a reference beam. Similarly, performance is not degraded by dirt or condensation from the atmospheric sample–as much as a 50 percent reduction in transmissivity can be tolerated. The mechanical components are not susceptible to vibration, and the solid-state electronic components are easily serviced.

Arkon Scientific Laboratories in Berkeley, California, under contract to the NASA Ames Research Center, first demonstrated the feasibility of using the dual isotope technique in 1966. The first prototype unit was made at Arkon in 1970, under contract to the National Air Pollution Control

Agency (now part of EPA). The technology was rapidly developed in 1970 and 1971, again under contract to Ames, to provide an operational CO analyzer for the Skylab cabin atmosphere. In 1972 Arkon was reorganized into Andros, Incorporated, to develop a commercial version of the Skylab monitor. A built-in zero point calibrator was added, slight design changes were made to meet EPA specifications, and the unit was marketed. In 1973, Andros sold this product line to Beckman Instruments, Incorporated, and Beckman is now selling the units as they were designed at Andros for approximately $6,800 each.

More than 30 of the instruments have been sold to government agencies and industrial firms. The California Air Resources Board and EPA are using the units for ambient, airborne, and automotive emissions air monitoring. For example, EPA used the instrument on a helicopter to measure the CO profile in the Los Angeles basin; no other CO analyzer could have been used in this fashion.

Dispersive Infrared Vehicle Exhaust Analyzer

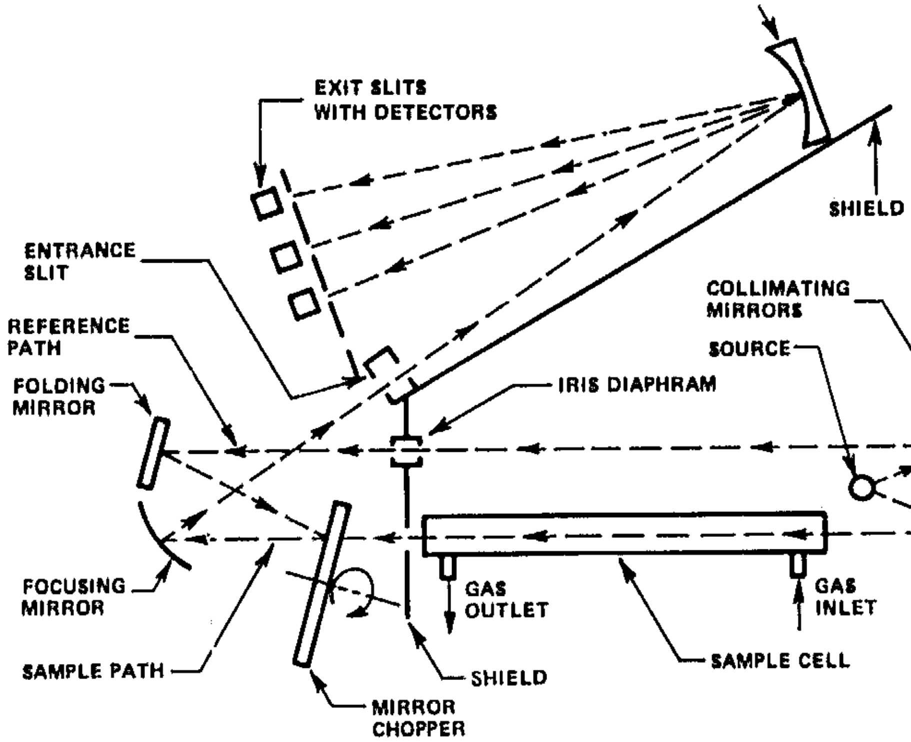
Nondispersive instruments transmit the complete electromagnetic spectrum within a given range through an atmospheric sample, and a filter in the unit selects the relevant absorption wavelengths for a specific pollutant gas. A nondispersive spectrometer must, therefore, be designed for a specific pollutant. A dispersive spectrophotometer, by contrast, contains a prism or grating to disperse a given range of the electromagnetic spectrum into small wavelength intervals either before or after the beam is transmitted through a gaseous or liquid sample. The dispersive unit could, therefore, simultaneously measure all pollutant gases having an absorbing wavelength within the unit's spectral range (Maugh, 1972). In either case, the infrared range is the most important for air pollution since nearly every significant gaseous air pollutant has at least one characteristic absorption wavelength in the infrared spectrum (Hodgeson, 1973).

Although a dispersive infrared (DIR) spectrophotometer has potential advantages–such as much lower total cost and simultaneous measurement of several gases in the same sample–over the multiple, specialized nondispersive infrared units it could replace, development efforts have not produced a DIR unit for ambient air measurement that performs to legal standards. The major technological barrier to developing a DIR spectrophotometer for ambient air pollution measurements has been the inability to discriminate between pollutants with wavelengths that are very close together (Hollowell, 1973).

While better resolution in the optical components and more sophisticated electronic design are needed to produce a DIR spectrophotometer for measuring ambient air, the limited number of constituent gases in vehicle emissions (primarily carbon dioxide, carbon monoxide, oxides of nitrogen, and hydrocarbons) has reduced the instrument design problems to a tractable, though still difficult, level. Both EPA and the state of California recently certified a new DIR unit for vehicle emissions analysis. This new DIR spectrophotometer was developed by Chrysler Corporation with technological expertise the company gained when it designed the Hazardous Gas Detection System (HGDS) for the Saturn-IB stage at the Marshall Space Flight Center's Saturn Systems Development Breadboard Facility (SDBF)–a facility the Chrysler Huntsville Division installed and has operated since 1961 The Hazardous Gas Analyzer is a computer-automated system to collect samples of fuel vapor, quantitatively analyze the samples, and display the data so that safety procedures can be followed in a timely manner.

The development of the DIR spectrophotometer for vehicle emissions analysis was initiated in 1968 by a small group of Chrysler engineers who had previously been associated with the HGDS. The Saturn-IB HGDS utilized a mass spectrometer to determine qualitatively and quantitatively the specific

gases under observation. Most of the adaptation effort focused on replacing the mass spectrometer with a DIR that could provide measurements of the particular gases in vehicle emissions and convert these measurements to a computer compatible signal. This new analytical system was ready by 1970 after approximately $200,000 had been invested (see Figure 2-2). It not only reflects aerospace technology in gas detection techniques but also in electronics, data handling and data processing.



The Vehicle Exhaust Analyzer system employs a gas sample conditioning subsystem to provide a sample gas flow, with water and particulate matter removed, to the optical subsystem. The dispersive infrared optical subsystem is a double-beam differencing system where both beams are derived from a single source of infrared radiation. One beam passes through the sample cell to the grating and the detectors; the second beam bypasses the sample cell and is the reference (unabsorbed signal) beam. Some of the radiation passing through the sample is absorbed. The absorbed wavelengths define one (or more) gaseous constituent present in the sample, while the amount of absorbed light is a measure of the concentration of that species present in the sample. The light beam passed through the sample is then dispersed into its component wavelengths by means of a grating; certain selected wavelengths are detected; and the signal strength is measured. The concentration of gas being measured is proportional to the difference between the two signal strengths at the lead selenide detectors. A mirror chopper alternately presents the sample and reference beams to the detector elements (Chrysler Corporation, 1972).

Figure 2-2. Dispersive Infrared Vehicle Exhaust Analyzer. [Source: Chrysler Corporation, 1971.]

The major advantage of this unit is that it simultaneously measures the concentrations of CO, CO_2, and hydrocarbons in a single sample, with automated sample manipulation needed to remove water vapor. Other operational advantages include simplicity, easy maintenance, reliability, and ruggedness, as

well as computer interfacing capability that allows several of the units to be used at a large certification test facility for new cars in California.

Chrysler has sold about 70 of the units at prices ranging from $15,000 to $50,000 depending on what specific instrumentation and automation components were used. The company's automobile divisions and General Motors, for example, are using these analyzers to test new car emissions in their research laboratories and after production.

Crysler Huntsville also developed a computerized Automated System for Emission Testing (ASET) that can coordinate up to seven of the vehicle exhaust analyzers in acquiring data, data analysis, emission analyzer status monitoring and emission analyzer control. The ASET computer controls the acquisition of data through the real-time process control interface based on predefined test descriptions and on-line operator or test conductor options. The computer then linearizes, scales, and integrates the source data prior to utilizing it to compute emission levels in grams per vehicle mile. Data is also presented in the form of concentration levels. The first ASET system has been installed for Automotive Pre-Check Corporation in Los Angeles, California to certify new cars in that state.

Microwave Spectrometer Formaldehyde Analyzer

Formaldehyde, a toxic, eye-irritating component of photochemical smog, is generally produced by the partial combustion of hydorcarbon fuels. Measurement of formaldehyde has been done with wet-chemical laboratory techniques, so on site monitoring of this pollutant has not been feasible. Other available techniques for monitoring formaldehyde do not satisfy EPA sensitivity requirements.

The EPA and NASA jointly funded the recent development of an advanced, operational formaldehyde monitor based on microwave spectroscopic technology that was originally developed at the NASA Langley Research Center for monitoring the atmosphere in spacecraft cabin simulators. The new portable unit is the first nonlaboratory instrument which is capable of measuring an air pollutant to EPA standards by using the microwave region of the spectrum (White, 1973).

Virtually all pollutants of interest, including formaldehyde, possess rotational absorption lines in the microwave region. The microwave spectrum provides an even more specific fingerprint of a moleule than the infrared spectrum due to the narrowness of the rotational line and the accuracy with which its frequency can be measured. Microwave spectroscopy has not been applied in earlier quantitative air pollution measurements because of the complex nature of available microwave systems, the low rotational absorption coefficients and resultant poor sensitivities, the low pressure requirements, and the high metallic surface area inherent in conventional microwave absorption cells (Hodgeson, 1973).

Microwave spectrometers are generally operated at low sample pressures–typically about 10^{-2} torr–to prevent collisional broadening of absorption bands. At such pressures, however, the absolute number of pollutant molecules is so small that detection of ambient concentrations of pollutants requires an unreasonably long microwave cavity or wave guide to provide a sufficiently large sample (Maugh, 1972).

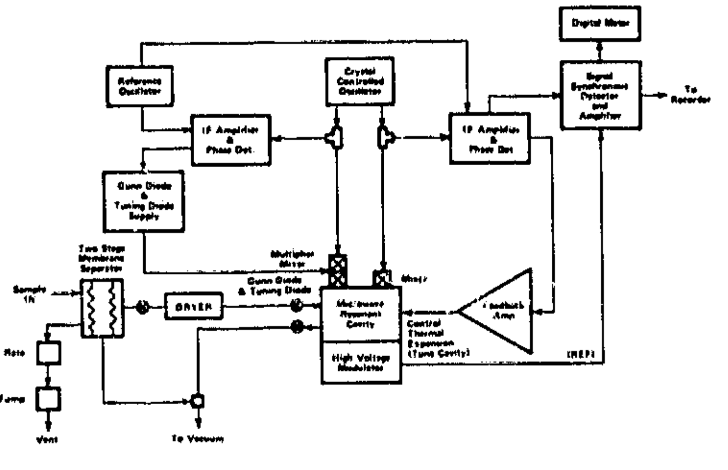
The Langley Research Center started developing microwave spectroscopy in the early 1960's to measure gaseous contaminants in spacecraft simulation chambers. Microwave spectroscopy for gas analysis was not well developed at that time, but a microwave instrument offered the best potential for selective measurement of the many interfering gases in a chamber. Researchers at Langley developed

microwave instrumentation, design analysis techniques, and data for interpreting the microwave spectra of many molecular species. The center currently maintains one of the only computer-based reference data systems for microwave spectra in the United States.

Until 1971, th focus of the Langley microwave instrument design work was on laboratory-sized units. In January of that year, the NASA Technology Application Team (TATeam) at the Research Triangle Institute (RTI) in North Carolina, in cooperation with scientists at the nearby EPA National Environmental Research Center, distributed a problem statement describing EPA's requirements for a portable microwave spectrometer to measure formaldehyde. The desired instrument was to cost less than $5,000 and provide, in less than one minute, measurements for concentrations of formaldehyde in ambient air as low as 0.01 ppm and in vehicle exhaust as low as 0.1 ppm.

As a result of the TATeam problem statement, researchers from Langley and the EPA group began an effort to adapt the Langley microwave technology to develop a portable instrument. The first design of this unit was breadboarded at Langley, and feasibility tests were successfully completed. The test results indicated that a microwave instrument meeting the EPA requirements could be developed.

More design work was needed, however, to develop an operational unit. A scientist at the Lawrence Livermore Laboratory in California, who had developed a small solid-state microwave source in his dissertation research, was identified by Langley experts as the appropriate principal investigator to develop an operational spectrometer. The NASA Technology Utilization Office and EPA each provided about $55,000 for the subsequent development effort, and a completed instrument was delivered to EPA in January 1974 for final evaluation (see Figure 2-3).



In this schematic of the Lawrence Livermore Laboratory spectrometer, a resonant cavity is coupled to a small, solid-state, Gunn-diode microwave source. The resonant cavity provides a long, effective path length (15 centimeters) at minimum volume and internal surface area. Thermal expansion is used in a feedback loop to control cavity dimensions and, thus, the resonant frequency. Conventional Stark modulation of the sample and synchronous detection at the modulation frequency are used to measure small changes in microwave power due to sample absorption. A two-stage membrane separator is used on the inlet to preconcentrate the pollutant by more than two orders of magnitude. Without the separator, this unit has a sensitivity of about 1 ppm (Hodgeson, 1973).

Figure 2-3. Microwave Spectrometer Formaldehyde Monitor. [Source: Hrubesh, 1973.]

Commercial firms have already expressed their interest in the new microwave spectrometer to the Laboratory, but final evaluation tests will be conducted by EPA before commercial development proceeds. In the meantime, the Laboratory is designing dedicated microwave units to monitor ammonia and sulfur dioxide. Preliminary tests indicate the same technology can also be used for a nitrogen dioxide monitor. Even without the separator membranes, the microwave instrument has a sensitivity in the low parts per million range for these three pollutants (Hodgeson, 1973). A Hewlett-Packard Corporation scientist in Palo Alto, California has estimated that multipollutant microwave spectrometers based on the same designs could be commercially available in two years (Maugh, 1972).

Conclusion

The three examples described in this section illustrate how NASA's unique requirements for monitoring gaseous contaminants were satisfied by the development of new spectroscopic techniques. These NASA-developed techniques are now embodied in new air pollution monitoring instruments which are at the leading edge of a major trend toward spectroscopic measurement. The exacting demand for aerospace instrumentation forced advances in the state-of-the-art which are, in turn, supporting the implementation of the Clean Air Act of 1970. Attachment I contains additional examples of NASA-generated technology now finding commercial application in the development of equipment for pollution measurement and control.

SECTION III. SELECTED NASA CONTRIBUTIONS TO ENVIRONMENTAL MEASUREMENT BY SATELLITE REMOTE SENSING

One of the most significant contributions of the National Aeronautics and Space Administration toward understanding, describing, and predicting the state of the environment is that of providing the ability to view the earth and its resources in a novel way–by means of an orbiting satellite.

Satellite measurements offer a number of advantages over ground-based and aircraft observations. First, they provide a synoptic overview of a region. For example, a single picture obtained from the Earth Resources Technology Satellite (ERTS-1) shows the entire Tidewater area of Virginia, from Norfolk to Washington, D. C. Second, a satellite measurement can often yield broad-scale information concerning a variety of phenomena. The same imagery used by a hydrologist to estimate snow pack in a mountainous region might also be employed by a forestry official to help determine the effects of smog on the vegetation of the area. A third, and perhaps most important, advantage is that satellites provide the opportunity to obtain relatively inexpensive measurements on a global basis:

> A principle reason for the importance of remote sensing is the need for the collection of data on a scale and with a coverage either prohibitively expensive or virtually impossible by conventional or direct means. . . . An earth orbiting satellite covering the entire globe of the earth once every 12 hours in a polar orbit can provide a coverage which has never before been possible with local sensors because the resources to install and operate such a vast network never have been–and in all probability never will be–available for that purpose (Yates, 1972).

This section focuses on three NASA contributions that illustrate the ways in which the advantages of satellite-based measurements are brought to bear on problems of environmental pollution. They include: (1) satellite vertical temperature profile measurements, involving operational technology that provides useful information on a daily basis; (2) pollution measurement experiments associated with ERTS-1; and (3) research being undertaken for the eventual measurement of atmospheric pollutants on a global basis. Additional applications of NASA-generated remote sensing technology in pollution measurement and control are given in Attachment I.

Satellite Vertical Temperature Profile Measurements

In any effective air pollution control program, meteorological data and weather forecasting capabilities are of central importance. The ability to predict the weather is important not only to metropolitan air pollution control officers but also to plant operators concerned with the dispersal of stack effluents. This is due to the fact that most pollution problems arise when the air is stagnant, and weather forecasting provides useful predictions of wind direction and velocity, the possibility of temperature inversions and other meteorological data.

Accurate weather forecasting relies heavily on the integration of a variety of measurements such as wind speeds, humidity, and air and ground temperatures. One measurement that is crucial to achieving precise meteorological predictions is the vertical temperature profile of the air, or the temperatures of the air at different heights above the ground.

For many years these measurements have been made by radiosondes, balloons which report altitude and temperature data. In 1969, the Satellite Infrared Spectrometer (SIRS) on board Nimbus 3, one of a series of NASA research and development weather satellites, began to provide measurements

which scientists were able to reduce to vertical temperature profile soundings. This spectrometer provided useful data in cloud-free areas, but it was not effective when partial cloud cover was present. The Nimbus Program subsequently developed a more refined instrument, the Vertical Temperature Profile Radiometer (VTPR), that could obtain useful profiles under partly cloudy conditions. The VTPR is now being used aboard NOAA-2 and NOAA-3, the National Oceanic and Atmospheric Administration's two most recently launched operational weather satellites. Since these satellites can scan 85 percent of the globe, timely vertical temperature profile data are not only being relayed to the U. S. National Weather Service but also to users in many countries. Figure 3-1 shows the good correlation between vertical temperature profiles obtained by radiosonde and those determined using soundings from NOAA-2.

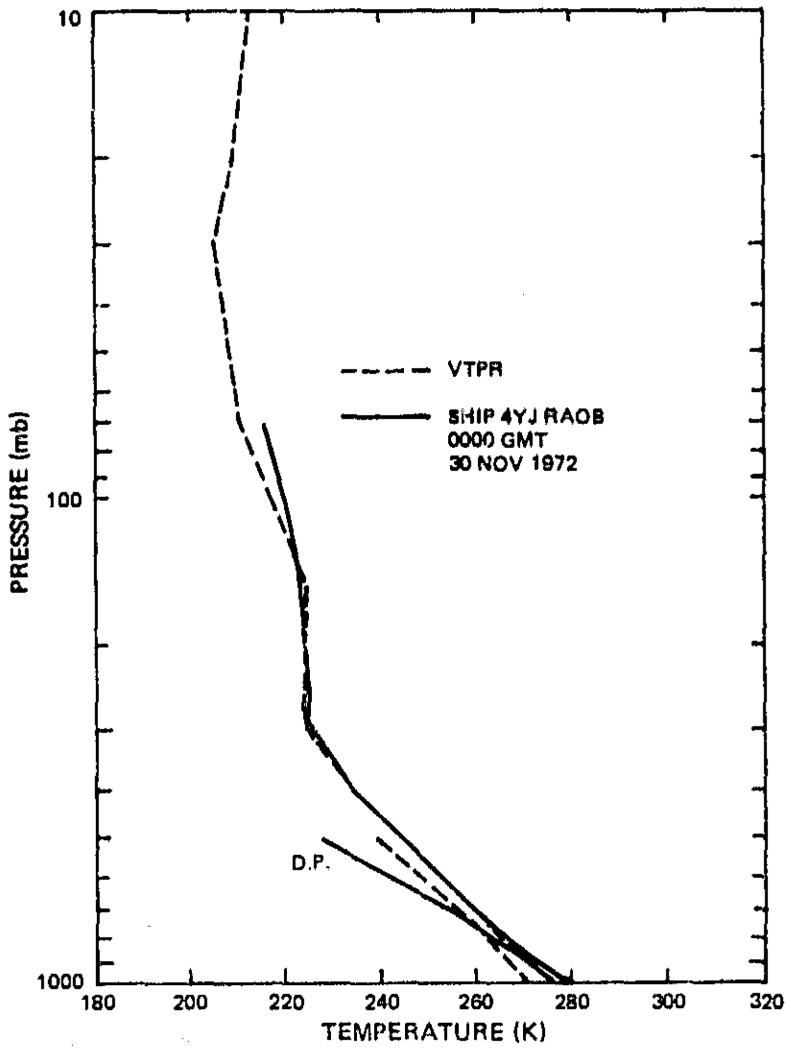
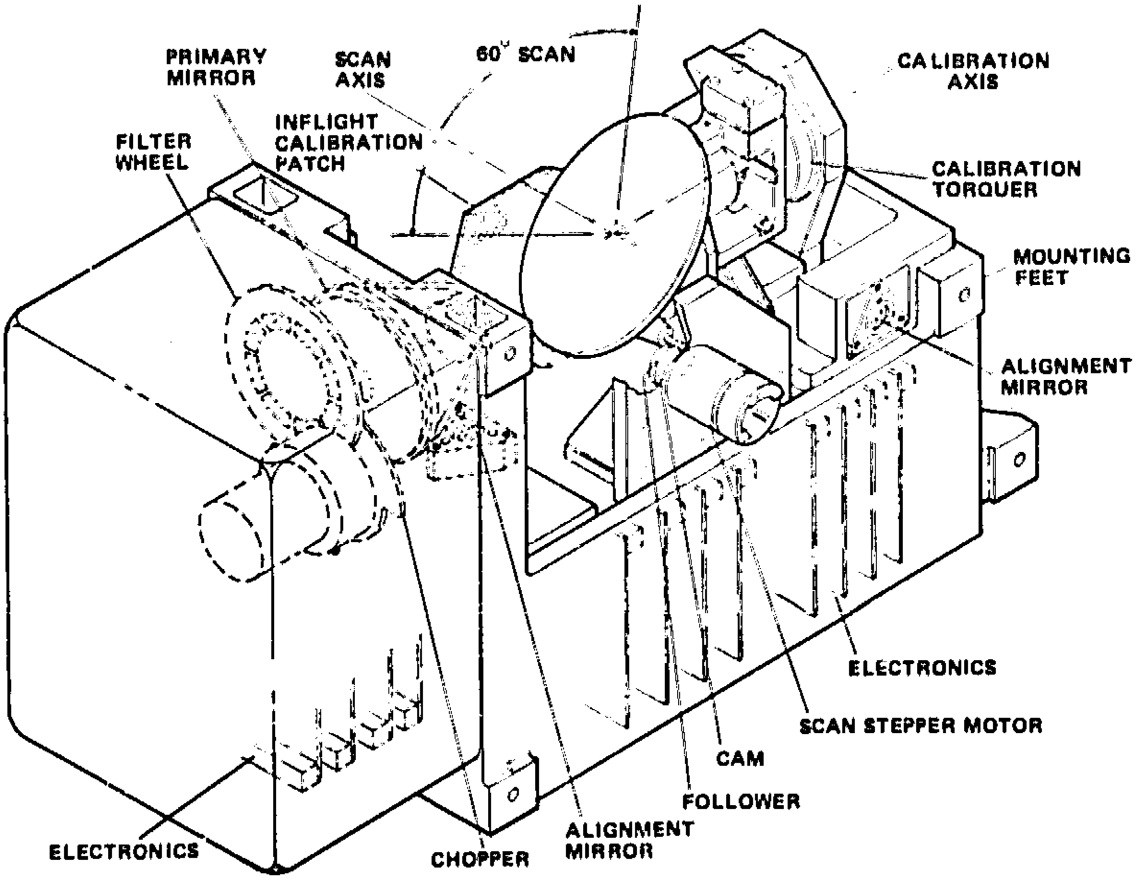


Figure 3-1. Comparison Between a VTPR Sounding and a Radiosonde at 52.5° North, 20° West (D.P. indicates dewpoint). [Source: McMillin, 1973.]

A diagram of the VTPR now being used on the NOAA satellites is presented in Figure 3-2, along with a discussion of the general principles upon which current satellite vertical temperature profile measurements are based.



Satellite vertical temperature profile measurements take advantage of the spectral properties of carbon dioxide. Among the constituents of the atmosphere, carbon dioxide is the only emitter of radiation in the region of 15 microns; measurement in this part of the spectrum is due almost entirely to the gas. The intensity of the emitted radiation depends on three factors: the mass of the gas, an absorption coefficient, and the temperature of the gas.

Because carbon dioxide is present in a fixed ratio (0.04 percent) and is distributed uniformly throughout the atmosphere, its mass at any given height is known. The absorption coefficient is different for different pressures and for different radiation wavelengths. As a result, radiation at a certain wavelength can be attributed to the carbon dioxide at a known pressure (hence, at a known height) in the atmosphere. Since the mass of carbon dioxide at this height is known, the radiation intensity at a given wavelength will provide the desired measurement of the temperature at a given height.

Figure 3-2. Isometric View of a VTPR Instrument. [Source: McMillin, 1973.]

NASA is also pioneering the development of instrument to provide even better vertical temperature profile coverage. A spectrometer which measures the radiation emitted by oxygen rather than carbon dioxide and which operates in the microwave rather than the infrared region of the spectrum is now being tested on Nimbus 5, NASA's newest weather research satellite. The principle advantage of the microwave region is that scattering by clouds and aerosols is orders of magnitude less than in the infrared. A recent report indicates that this new instrument can provide accurate temperature profiles even under overcast conditions (Staelin, 1973).

Although satellite soundings are already being used in the preparation of daily forecasts, their full potential is just beginning to be realized. The significance of satellite vertical temperature measurements is seen when these first generation operational satellites are compared with balloons in terms of the coverage obtained and the relative cost of the measurements. Radiosondes produce about 1,000 soundings per day (largely clustered in the more technically advanced countries, with polar areas and oceans having extremely sparse coverage) at an average cost of over $100 per sounding; by contrast, the present satellite system is capable of producing about 2,500 soundings per day (distributed evenly over the globe) for about $10 per sounding (Spohn, 1972). As operational sensor devices and methods of data reduction and analysis improve, the importance of satellite measurements will continue to grow.

Pollution Measurement Experiments Associated with ERTS

The Earth Resources Technology Satellite, ERTS-1, is an excellent example of one of the ways in which NASA's capabilities in satellite technology and its continued support of remote sensing programs are now being applied to environmental problems. While there are more than fifty ERTS experiments associated with water and air pollution measurement, only three will be discussed here to illustrate the present utility and the future promise of satellite remote sensing of pollutants.

Monitoring pollutants in coastal waters. Ocean dumping of objectionable waste products that are difficult or expensive to treat is increasing rapidly. In many cases, these wastes are not discharged in deep waters, but in more shallow coastal areas where they can pose a serious pollution hazard.

A study was conducted by the Environmental Research Institute of Michigan, in cooperation with NASA, to evaluate the potential of remote sensing for monitoring disposal of waste materials in the oceans. The coastal waters between northern New Jersey and Long Island, the New York Bight, were chosen as the study area. This particular body of water is used extensively as a dumping ground for wastes from the New York metropolitan region. For example, over 10,000 cubic yards of sewage sludge are disposed of daily in an area about 12 miles south of Long Island. In addition, acid-iron wastes are dispersed by barge over a haripin-shaped course in the same general region.

ERTS-1 imagery of the area, acquired on August 16, 1972, was analyzed and compared with aircraft overflights on the same day. The satellite imagery, shown in Figure 3-3, correlated well with the aircraft data and clearly identified the acid waste discharges and the sewage sludge dump area. Because the satellite instrument provided scans in different regions of the spectrum, it was possible to obtain additional information–in particular, the water mass boundaries and the relative depth of the sewage sludge. Furthermore, the shape of the waste discharge plumes and the water boundaries provided information regarding the surface circulation patterns at the time of discharge (Wezernak, 1973).

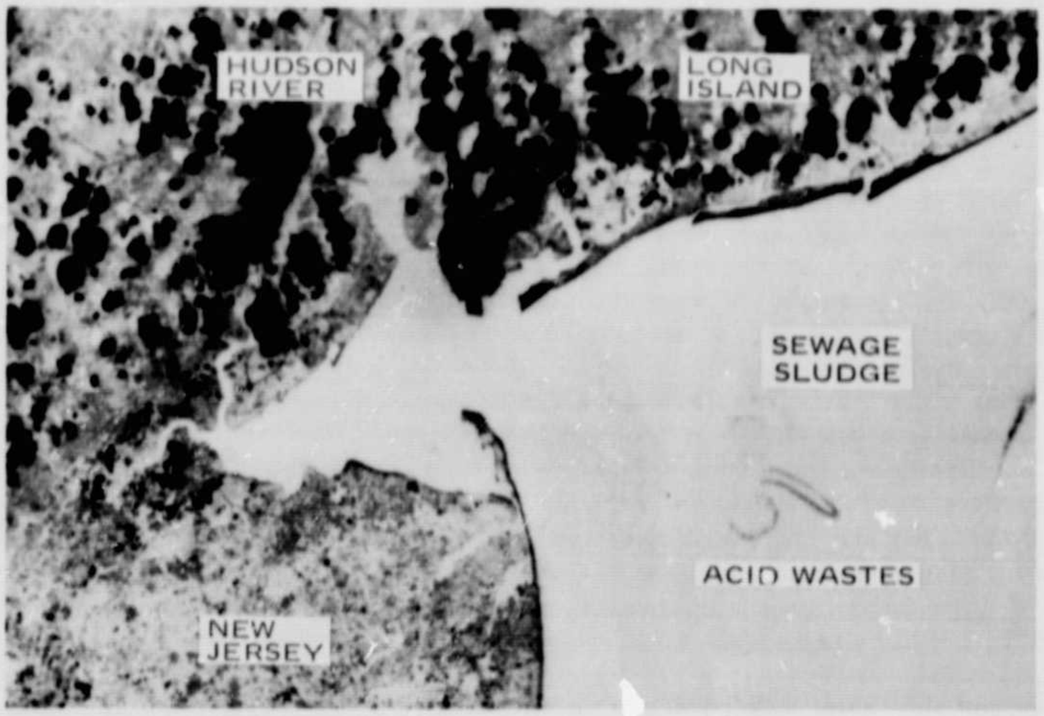


Figure 3-3. ERTS-1 Imagery of the New York Bight. [Source: NASA, 1972.]

While the satellite data did not give a great deal of quantitative information about the composition or concentration of the various pollutants, it did provide useful information on the geographic location of the various materials. It was found, for example, that the distance from the nearest point of the acid waste plume to the New Jersey coast was closer than the designated dump area. In addition, the total area of the sewage sludge and acid-iron waste dumps could be measured.

Monitoring lake pollution. In an experiment conducted by scientists at the University of Vermont, it was found that ERTS-1 imagery of Lake Champlain could be used to map a major pollution plume which had apparently been caused by waste discharges from a new paper mill near Fort Ticonderoga. The satellite data provided a synoptic overview which, together with ground-based and aircraft data, showed that the plume did indeed extend into Vermont waters (Lind, 1973). The state of Vermont initiated legal action against both the paper company and the state of New York, alleging that the new plant was reducing the water quality of the lake below Vermont standards and that polluted water was crossing over the state boundary into Vermont (Graham, 1972). Although the suit is still before the U. S. Supreme Court, it is significant that both ERTS-1 imagery and the interpretation of the imagery have been accepted as legal evidence in the case (Lind, 1974).

These experiments, as well as others now underway, are clearly demonstrating the utility of satellite remote sensing for providing accurate and relatively inexpensive water pollution measurements that can be a part of a broad-scale water quality program.

Remote sensing of air pollutants. ERTS-1 experiments are also demonstrating the feasibility of utilizing satellite remote sensing systems in the monitoring of air pollution. In a study conducted at Old

Dominion University, Norfolk, Virginia, scientists showed that ERTS data could be used to detect aerosol plumes in the atmosphere (Copeland, 1973). They found that the measurement of a plume's reflectivity—a densitometer scan—helped to provide qualitative information on the character of the plume. This was possible because different types of plumes have different reflective characteristics.

This study is also showing that, by means of satellite monitoring, it might be possible to acquire quanitative data on smoke stack emissions over state-size regions. By correlating ERTS imagery with known stack locations, actual emission data, and meteorological conditions, atmospheric diffusion coefficients can be computed and a model developed to predict surface emission concentrations. This model is currently being verified and refined by on site measurements using a mobile laboratory.

Other studies indicate that satellite imagery might be used to obtain estimates of stack emission rates. This would provide a means of monitoring known sources of air pollution at a great reduction in cost, as compared to other methods. Although such satellite measurements do not completely obviate the need for ground-based instruments, the number of these instruments could be considerably reduced. For example, by using satellite measurements to determine potential areas of high particulate concentration, a pollution control board could develop monitoring strategies that would permit the most effective deployment of ground-based instruments. In addition, remote sensing provides a broad view of an entire region that is so important to a comprehensive pollution control program.

Measurement of Atmospheric Pollutants on a Global Basis

Millions of tons of carbon-, nitrogen- and sulfur-oxides are discharged into the atmosphere every year as a result of industrial processes. NASA is conducting research aimed at achieving, on a global basis, the monitoring of these relatively long-lived gaseous pollutants.

For the past three years, the Langley Research Center has supported a program called the Carbon Monoxide Pollution Experiment (COPE). This program is designed to determine the feasibility of using satellite-based instruments to obtain a global map of carbon monoxide (CO) that would not only indicate areas of higher than normal CO concentration, but it would also indicate areas where the CO concentration is significantly lower than normal (sinks). A map showing sinks is very useful in determining the means by which a pollutant is destroyed or removed from the atmosphere (e.g., by soil microorganisms). An instrument designed to map sinks must be considerably more sensitive than one needed to obtain the usual pollution maps, where only ambient and higher than ambient concentrations are plotted.

A correlation interferometer is being tested as a primary device for measuring concentrations of CO. The instrument was developed as part of a NASA-supported program by Barringer Research, Limited, on a subcontract from General Electric. It utilizes a correlation technique in conjunction with an interferometer, rather than a conventional spectrometer. An interferometer has an advantage over a spectrometer in that its throughput of energy is about 100 times greater.

The conventional interferometer has a number of disadvantages, the most serious being that data are presented in a graphic form. This requires a time-consuming computer analysis to obtain a high resolution, high intensity spectrum that is amenable to further interpretation. The weight and power requirements for such a complex analysis make the instrument unattractive for use on board a spacecraft. A further drawback is that the analysis involves a step which tends to magnify out of proportion the contribution of noise present in the original signal.

These drawbacks are eliminated in the correlation interferometer. The interferogram obtained by the sensor is correlated with stored replicas of the interferograms of various mixtures of the gas being detected. Since it is not necessary to convert an interferogram to a conventional spectrum, the data processing is greatly simplified (Barringer and Davies, 1971).

In order to determine the feasibility of using such an instrument in orbit, two critical questions needed to be answered:

- Can the desired information be obtained from measurements made from a satellite where factors such as the atmospheric temperature profile, earthshine, and atmospheric absorption and emission must be taken into account?

- Which of the absorption wavelengths for carbon monoxide would provide the most reliable and usable results?

The Space Sciences Laboratory of the General Electric Company, under NASA contract, obtained answers to these questions. Ten different carbon monoxide profiles were used in their computerized simulation study. For example, profile 1 was for a constant mixing ratio of 100 parts per billion (ppb), while profile 5 represented a low altitude sink having a mixing ratio of 10 ppb at zero kilometers and 100 ppb at 9 kilometers.

This study concluded that it appeared feasible to use a satellite-based correlation interferometer to obtain a global map indicating carbon monoxide sources and sinks. It was also found that 2.3 microns was the most suitable wavelength for measurements (Bortner, October 1973). In addition, the instrument was shown to be suitable for obtaining the same information about methane (Bortner, March 1973).

A breadboard correlation interferometer was built and laboratory tested on gas sample cells containing various concentrations of carbon monoxide and other pollutants. These laboratory studies have indicated that the instrument has sufficient sensitivity and specificity to map carbon monoxide concentrations in the atmosphere and to distinguish between the different models that predict the carbon monoxide concentration (Becker, 1972). An engineering model of the instrument has been constructed and is presently being tested on board an aircraft (Bortner, 1974). A correlation interferometer for the measurement of atmospheric trace species is now being designed for possible use on a pollution monitoring satellite that is being considered for launch in the late 1970's.

Closer at hand, NASA's next research and development satellite, Nimbus G (Nimbus 6 once it is placed in orbit), has as a primary mission objective detecting, identifying, mapping, and measuring of air and ocean pollution. Measurements will be used to establish baseline levels so that long-term trends can be determined and to provide information about location, movement and fate of pollutants.

Three sensor systems will be used for air pollution measurements. One will measure ozone, water vapor, nitric acid, methane, nitrous oxide, and nitrogen dioxide in the stratosphere, together with the temperature where they are found. A second instrument is designed to measure carbon monoxide, sulfur dioxide, ammonia, and methane in the troposphere. A visible polarimeter will also be on board to measure the composition, size, and distribution of particles in the atmosphere (U.S. Congress, 1973).

Conclusion

This section has served to illustrate that by actively supporting R&D in satellite remote sensing, NASA is making an important contribution to society's efforts to control pollution. Satellite remote sensing, through NASA program achievements, is now a viable means of broad-scale measurement and global monitoring. These measurements provide information on pollution and its effects that are proving to be an integral part of the national program of pollution control and abatement.

SECTION IV. A PERSPECTIVE

Two distinct ways in which aerospace technology is being utilized to satisfy new requirements in pollution measurement have been examined in this report: the application of instrumentation innovations in designing improved air pollution monitoring equipment and the use of satellite-derived data to develop broad-scale measuring capabilities. While the new instrumentation is providing the sensitivity and selectivity required by national pollution standards, satellite remote sensing is establishing a fundamentally new way of monitoring the environment on a global basis.

These contributions clearly demonstrate how the technology developed to meet specific mission requirements of the National Aeronautics and Space Administration is also being used to meet another national commitment—the quest for an improved environment.

ATTACHMENT I

Summaries of Technology Transfer Examples Involving NASA-Generated Technology for Pollution Measurement and Control

SUMMARIES OF TECHNOLOGY TRANSFER EXAMPLES INVOLVING NASA-GENERATED TECHNOLOGY FOR POLLUTION MEASUREMENT AND CONTROL

NASA CONTRIBUTIONS	TRANSFER STAGES							
	1		2		3		4	
	Cont.*	Term.	Cont.	Term.	Cont.	Term.	Cont.	Term.
POLLUTION EFFECTS								
• Estimating Carbon Monoxide Exposure				77452**				
POLLUTION MEASUREMENT								
• Correlation Spectrometer for Air Pollution Remote Sensing							95608	
• Heat Pipe Applications					90555			
• Analytic Technique for Organic Water Pollutants					96529			
POLLUTION MODELING AND ABATEMENT								
• Telemetry Systems for Remote Monitoring							96532	
• Environmental Models and Analysis							96531	
• Weather Satellite Data for Air Pollution Control					78001 96526			
• Computer Programs to Analyze Combustion			86011 86013 86015 93826		86010 86012 86014 86016 86018 93825		86009	
• Fuel Vaporization Model			87030				87029	
• Coal Desulfurization Process			96530					
• Applications of Reliability and Quality Assurance in the Offshore Petroleum Industry					93829 93831 93830		96528	

*The action status, continuing or terminated, of transfer cases at the time DRI-TRIS contacted users. Cases are classed as terminated when (a) no further adaptation or adoption is contemplated, (b) a better technical alternative has been found, or (c) continued transfer activity is not economically feasible.

**Numbers in columns refer to TRIS case numbers.

ESTIMATING CARBON MONOXIDE EXPOSURE
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The North American Rockwell Corporation, under contract to the Lyndon B. Johnson Space Center, conducted a study of the nature of carbon monoxide (CO) poisoning on astronauts in order to develop design and operating criteria for spacecraft. As a result, a novel method for predicting the effects of CO exposure on humans was developed. Precise correlations of carbon monoxide poisoning, breathing rates, and variations in atmospheric conditions were established.

Two equations were developed which make it possible to estimate the carboxy hemoglobin formed when CO is inhaled and to determine when adjustments for pulmonary ventilation are necessary. The study results indicated a need to maintain a low CO toxicity level, less than 17 milligrams per cubic meter, in spacecraft cabin atmospheres. Unusual generators of CO, such as paints and activated charcoal, were also described in the study report. This report was announced by NASA in Tech Brief 71-10319, entitled "Estimating Carbon Monoxide Exposure."

Aerospace American, Incorporated, a manufacturer of fork lift trucks and other off-the-road equipment in Bay City, Michigan (77452), used the NASA Technical Support Pakcage (TSP) in its product modification program to reduce CO emissions. The TSP was a major source of information for the company, showing the necessity of its program and suggesting future directions. To date, approximately $10,000 has been spent in this research effort, and company engineers are now considering ways to use automotive emission control equipment in company products. A company spokesman indicated that both time and money have been saved by using the NASA information.

Control Numbers

Tech Brief Number: 71-10319
NASA Center: Lyndon B. Johnson Space Center
TRIS Case Number: 77452
TEF Number: 461
Date of Latest Information Used: January 5, 1973

CORRELATION SPECTROMETER FOR AIR POLLUTION REMOTE SENSING TECHNOLOGY TRANSFER EXAMPLE SUMMARY

In the mid-1960's, Barringer Research, Limited, in Rexdale, Ontario (95608) designed and built a prototype correlation spectrometer for measuring air pollutants in stack gases. This work was done with in-house funding and under a contract with the American Iron and Steel Institute. Substantial design improvements and flight testing for calibration were needed to develop this instrument into a satisfactory, airborne remote sensor for air pollutants.

Barringer was subsequently funded by the Lyndon B. Johnson Space Center to develop an operational remote sensor for sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) by modifying the prototype design. NASA contracted with Barringer to conduct flight tests for the new instrument over San Francisco and Los Angeles to measure nitrogen dioxide profiles and over Chicago to measure the sulfur dioxide profile. The Chicago profile was done with a high altitude balloon to evaluate the instrument for possible use on board a spacecraft. Favorable results were obtained.

Barringer has sold 38 correlation spectrometers at prices between $23,000 and $24,200 each. The instruments are being used remotely to measure SO_2 and NO_2 by air pollution control agencies in the U. S., Canada, Australia, Japan, Netherlands, France and Spain. The pollutant profiles provided by the Barringer product, which are important inputs to the development of pollution control strategies, cannot be obtained by any other commercial instrument.

Control Numbers

Tech Brief Number: None
NASA Center: Lyndon B. Johnson Space Center
TRIS Case Number: 95608
TEF Number: 482
Date of Latest Information Used: August 31, 1973

HEAT PIPE APPLICATIONS
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The development of modern heat pipe technology was initiated in 1963 by George Grover of the Los Alamos Scientific Laboratories. The Atomic Energy Commission secured a patent only on the high-temperature heat pipe because it was discovered during a patent search that a similar device had been patented in 1942 for refrigeration uses. Grover's heat pipe was developed specifically to solve spacecraft thermal equilibrium problems. Sun facing surfaces of nonrotating satellites become excessively hot, while surfaces not exposed to the sun become very cold; the temperature differentials can cause failure of electronic and other spacecraft systems. One solution is to rotate the spacecraft, but in some satellite uses this is not possible or desirable. Grover's system transfers heat efficiently without recourse to pumps or other mechanical devices that might be subject to failure.

The heat pipe is a simple device, involving no moving parts. A mesh, or wick, is sealed inside a tube along with a working fluid. When heat is applied to a portion of the pipe, the working fluid evaporates and fills the pipe, condensing on the walls at cooler segments of the pipe. This condensation releases heat. Pressure and temperature differentials within the pipe are small, and the heat transfer occurs almost isothermally. The isothermic characteristic makes possible a return flow of the condensed fluid by capillary action, completing the cycle. The heat pipe can operate over a wide temperature range depending on the nature of the working fluid, which can be water, molten metal, or any other appropriate fluid. Heat can be transferred with a heat pipe up to 500 times more efficiently than with any solid metal conductor.

Since the announcement of Grover's invention, NASA and several private companies have been investigating numerous fluids, geometry, wick materials, and operating characteristics of the heat pipe. NASA has also sponsored colloquia to describe the rapidly expanding heat pipe technology. The NASA-sponsored Regional Dissemination Center at the University of New Mexico, the Technology Application Center (TAC), provides heat pipe bibliographies and symposia.

Gas analyzers used for air pollution monitoring must be very carefully calibrated to obtain valid data. The U. S. Department of Health, Education and Welfare (HEW) developed a technique using permeation tubes for calibrating these instruments. The National Bureau of Standards (NBS) has available a set of standard reference tubes of different gases that can be used with the HEW technique. In some cases, the NBS stamp signifying calibration to the standard is required by law or by the Environmental Protection Agency's (EPA) regulations.

Kin-Tek Laboratories, Incorporated, a small manufacturing firm in Texas City, Texas (90555), holds a license from HEW to produce a calibration device that embodies the HEW technique. Since the NBS standard reference gas data are for temperatures between 20°-30°C, the device must be cooled when the ambient temperature is above this range. Kin-Tek was evaluating methods for adding a cooler to its product and found that reliable cooler controls would add substantially to the price. The president of Kin-Tek used the Small Business Administration's Technology Utilization services to identify a number of NASA documents describing heat pipes. Using the basic ideas and data from the NASA literature, he developed a small heat pipe to adjust the calibration device temperature up to the proper level, thus eliminating the need for an expensive cooler control unit. Kin-Tek developed its own sealing method for heat pipes and produces the heat pipes used in its calibration equipment.

The firm expects to sell about 200 calibration devices in 1973. Only those customers that require an NBS stamp, such as EPA, will purchase the cooled unit with the heat pipe temperature moderator. However, these units are the ones that are directly related to compliance with air pollution emission standards. For industrial applications, the firm has created new permeation tube designs for special uses and has further developed the tube technique to use additional materials such as methane.

Control Numbers

Tech Brief Number: None
NASA-AEC Center: Los Alamos Scientific Laboratories
TRIS Case Number: 90555
TEF Number: 197
Date of Latest Information Used: April 18, 1973

ANALYTIC TECHNIQUE FOR ORGANIC WATER POLLUTANTS TECHNOLOGY TRANSFER EXAMPLE SUMMARY

In 1964 under contract to the Lyndon B. Johnson Space Center, the Rocketdyne Division of North American Aviation, Incorporated, in Canoga Park, California (96529) developed an advanced laboratory instrument to monitor all trace contaminants in the Apollo Command Module water systems during simulation tests. A new analytic technique, pryolytic gas chromatography with an associated computer analysis program, was designed and built as part of the laboratory monitor. This technique was used to measure directly the total organic content in the Apollo water samples without any requirement for pretreatment. Standards and calibrations for the organic pollutant monitor were established at North American in accordance with conventional gas-chromatograph procedures.

Between 1968 and 1972, the Environmental Protection Agency (EPA) and its predecessor in water quality research funded the same group of Rocketdyne instrumentation experts to develop a practical field instrument from the technology embodied in the Apollo water monitor. The main focus of this effort was on developing additional computer analysis programs to perform multicomponent pattern recognition techniques. By using these techniques, a computer can determine the concentration of known organic pollutants in the water sample. The prototype instrument for EPA was successfully tested on water pollutants from 20 industrial operations in the southeastern United States; prior to its development, the only instruments available for measuring organic water pollutants were laboratory-sized gas chromatograph/mass spectrometer combinations.

As a result of the size and speed of the new water monitor, the surveillance of waste discharges into streams and lakes might become practical. EPA is now using the prototype unit in water pollution investigations. A second prototype is also being used at Rocketdyne in oil pollution research and other water pollution programs.

Control Numbers

Tech Brief Number:	67-10243
NASA Center:	Lyndon B. Johnson Space Center
TRIS Case Number:	96529
TEF Number:	485
Date of Latest Information Used:	January 31, 1974

TELEMETRY SYSTEMS FOR REMOTE MONITORING
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The Reentry and Environmental Systems Division of the General Electric Company in King of Prussia, Pennsylvania (96532) developed telemetry systems for unmanned satellites, such as the Nimbus series and the Earth Resources Technology Satellite (ERTS-1), under contract to the Goddard Space Flight Center. These sophisticated telemetry systems digitize the data output from satellite instruments and transmit an organized data array to ground receivers. In addition, command signals are transmitted to the unmanned spacecraft to control instruments and data flows remotely. Weather and earth resources satellite telemetry systems process some of the largest remote monitoring data flow rates in the world.

The same GE division recently completed the development and installation of a computerized air pollution monitoring network, COPAMS, for the Commonwealth of Pennsylvania. This network provides Pennsylvania air pollution control officials with the technical capability to enforce state and federal primary air quality standards. The only major difference between the COPAMS telemetry system and those previously developed for satellites is in the communications link; COPAMS uses a special telephone party line while the satellites use radio transmissions.

The COPAMS hardware includes 32 monitoring stations distributed throughout the state, the telephone linkup to a central control station in the state capital, and a minicomputer with display and control equipment at the central station. Each monitoring station is a semipermanent building with instruments and electronics for measuring up to 16 air pollution and meteorological parameters. In the two-week intervals between regular maintenance visits, the 32 stations are remotely controlled through the telemetry system from the central computer. Commands can be sent to each station for certain routine maintenance functions such as calibration tests. Every 60 seconds the computer gathers data from each station's instruments. These data are automatically processed by the computer to provide hourly averages for different pollutants in conjunction with wind dispersion factors. The computer compares the averages to the state's primary air standards, and, if the standard is exceeded in some locality, the computer signals the operator to initiate the state's pollution control sequence. The sequence is defined by four levels of severity: advisory, alert, warning and emergency. The corresponding control actions range from public advisories to compulsory shutdowns of pollution sources until the pollution episode is over.

Control Numbers

Tech Brief Number: None
NASA Center: Goddard Space Flight Center
TRIS Case Number: 96532
TEF Number: 483
Date of Latest Information Used: February 12, 1974

ENVIRONMENTAL MODELS AND ANALYSIS TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The TRW Systems Group of TRW, Incorporated developed computer models, analyses, and other software for the Apollo program under contract to the Lyndon B. Johnson Space Center. These systems engineering applications included Apollo mission planning, trajectory simulation and Abort Guidance System software for the Lunar Module, and software testing and analysis for the Command Module's guidance and control computer. TRW also performed the data analysis for pre-flight testing of the Lunar Module Descent Engine and post-flight reconstruction of Apollo missions.

The TRW Environmental Services Development Division in Redondo Beach, California (96531) has used systems engineering expertise–developed by other TRW divisions for the space program–in designing more than 30 computer applications to environmental modeling and analysis. Most of these were done under contract to the Environmental Protection Agency to assist state and regional pollution agencies in implementing air and water pollution laws.

Some of the company's air and water pollution systems are: the Air Quality Display Model computer program which generates air pollution maps from meteorological data and an atmospheric diffusion model; Air Quality Implementation Plans to develop systematically regional pollution control plans based on stationary source inventories, atmospheric diffusion modeling, ambient air standards, and other factors; the Region Air Pollution Analysis program to evaluate progress in implementation plans and cost-benefit analysis for air pollution control; computer programs to establish optimum methods of automobile maintenance and inspection to reduce emissions; a computerized state air pollution data system; and water quality models for river basins. These analytic models have been applied in many localities, such as the District of Columbia, Alabama, Alaska, California, the Metropolitan Cincinnati Interstate Air Quality Control Region, South Carolina, and Vermont, to implement pollution control laws.

Control Numbers

Tech Brief Number: None
NASA Center: Lyndon B. Johnson Space Center
TRIS Case Number: 96531
TEF Number: 487
Date of Latest Information Used: January 30, 1974

WEATHER SATELLITE DATA FOR AIR POLLUTION CONTROL
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The Goddard Space Flight Center has had the primary responsibility for developing weather satellite instruments, telemetry systems, and ground station receiving equipment. One of the most important satellite to ground communication systems designed at Goddard is the Automatic Picture Transmission (APT) system. The APT system provides for automatic transmission of satellite sensor data to anyone with an inexpensive television-type ground station receiver. Although the original APT system only provided imagery in the visible range, the telemetry for subsequent infrared image sensors was designed so that APT receivers could be modified to display these data also. Thus, for example, output from the Satellite Infrared Spectrometer (SIRS) on board the NOAA-3 satellite is available to anyone with a modified APT receiver. Infrared imagery is used to determine vertical temperature profiles of the earth's atmosphere, a primary factor in predicting wind.

NASA has published two documents that give detailed instructions for building an APT receiver: *Constructing Inexpensive Automatic Picture-Transmission Ground Stations* (SP-5079) in 1968 and *Weather Satellite Picture Receiving Stations* (SP-5080) in 1969. The second publication also provides a detailed description of the receiver's operation. Using these plans, anyone with a basic knowledge of electronics could make his own receiver with parts costing under $500. An estimated 350 of these units have been or are being built for private, government, and research use around the world.

The National Environmental Satellite Service, part of the U. S. Department of Commerce in Suitland, Maryland (78001), distributes the satellite data from its APT receiver to a variety of users through National Weather Service facsimile networks. For example, the infrared data is integrated with other data from ground-based instruments to generate air stagnation maps that are used by local air pollution control officials to forecast air pollution dispersal. This output format and the related information processing techniques were developed for this purpose by the Environmental Quality Weather Service, a part of the National Weather Service.

The Air Pollution Control Division of the Colorado State Health Department in Denver (96526) receives facsimile maps from the National Weather Service for use in forecasting the duration of air pollution episodes. The division's meteorologist reported that Denver's air pollution is primarily a function of weather. In order to implement the four stage air pollution control sequence (advisory, alert, warning and emergency), the probable duration of local air stagnation must be projected to evaluate the trend in air pollutant concentrations. This trend determines the appropriate control level. On each occasion that the alert level has been announced, dispersal was predicted within four hours; the economic loss due to unnecessary industrial shutdown was avoided by accurate forecasting.

Control Numbers

Tech Brief Number:	None
NASA Center:	Goddard Space Flight Center
TRIS Case Number:	78001, 96526
TEF Numbers:	26, 194
Date of Latest Information Used:	October 18, 1973

PRECEDING PAGE BLANK NOT FILMED

COMPUTER PROGRAMS TO ANALYZE COMBUSTION TECHNOLOGY TRANSFER EXAMPLE SUMMARY

During the last 20 years government-sponsored research in combustion related to rocket propulsion has produced an extensive body of useful combustion technology. The Lewis Research Center played a prominent role in this effort from the beginning, and other NASA facilities participated through the 1960's. A very important type of NASA contribution to combustion technology has been the development of general computer programs to perform thermodynamic analyses of the combustion process. These programs fall into two general classes: equilibrium and kinetics.

A knowledge of chemical equilibrium compositions for a chemical system is basic to calculating the system's theoretical thermodynamic properties. One of the most widely used chemical equilibrium calculation programs in the United States, Chemical Equilibrium Calculations (CEC), was developed at the Lewis Research Center. After devising a practical calculation technique in the 1950's for high temperature chemical reactions with numerous products, Lewis researchers continued to update, generalize, and refine the basic CEC program. By 1971, CEC had become independent of the particular computer used, accurate with a built-in restriction from printing incorrect answers, general to the point that most chemical systems could be analyzed, and modular so that unnecessary subroutines for a particular problem could be bypassed. Constant volume, detonation, and shockwave phenomena could also be analyzed with CEC.

The wide scope of these developments exceeded the specific NASA requirements. This was done, in part, as a "community service" so that expanding computer capabilities could be utilized in equilibrium calculations by a large industrial community of interest. The basic thermodynamic data used as input to CEC can be obtained for over 500 chemical species from Lewis or generated by the user with another program (PAC-II) developed at Lewis. NASA announced the availability of the CEC program in Tech Brief 68-10025 and, in 1971, distributed a Special Publication (SP-273) which presented the program documentation along with several topics of general interest for chemical equilibrium analysis.

Chemical kinetic programs are used to analyze the performance of different combustor geometries and combusting techniques by calculating the exhaust gas expansion characteristics. Several important chemical kinetic programs were developed for NASA rocket research at TRW Systems, under contract to the Lyndon B. Johnson Space Center, and at the Lewis Research Center. The programs developed at TRW have been announced in four Tech Briefs: 68-10374, 68-10375, 68-10376 and 68-10377. These programs calculate the expansion of combustion produced gaseous mixtures, including condensed products, for different fuel compositions, combustion temperatures, relaxation rates and nozzle geometries. The calculation method (second order implicit integration) permits computation times that are several orders of magnitude less than standard explicit methods. These programs were subsequently standardized and refined for the Interagency Chemical Rocket Propulsion Group to provide a one-dimensional and a two-dimensional chemical kinetics program.

In addition to the specific programs described above, combustion research was conducted for NASA by other in-house, commercial and interagency government groups. In 1970 several researchers involved in these efforts, including the principal investigator from TRW Systems, formed a new company, KVB Engineering, Incorporated, in Tustin, California (86009). Since then, KVB has become a major combustion consulting firm for the electric power industry.

The kinetics and CEC programs are routinely used by KVB to analyze alternative fossil-fueled combustion techniques such as delayed mixing, premixed off-stoichiometric flames, off-stoichiometric diffusion flames (secondary combustion) and flame temperature control. This analysis predicts where oxides of nitrogen (NO_x) will be formed in the combustion chamber, identifies what mechanisms are involved, and describes the affect of change in combustion techniques for the specific chamber being analyzed. The results are used as a guide in selecting new operating procedures for burners so that the production of NO_x is minimized. This method has been used to reduce NO_x emissions from fossil-fired power plants by 40 to 70 percent. It is considerably less expensive than other proposed methods, such as catalytic or electrolytic reduction. Several electric utilities and equipment manufacturers have utilized the KVB consulting service in their efforts to comply with stringent NO_x emission standards. NO_x is an important component of photochemical smog, and its production in the combustion process is primarily a function of flame temperature.

The Southern California Edison Company in Los Angeles, California (86010) was the first utility to use the KVB service. The company has reduced NO_x emissions by 50 to 70 percent in each of its 22 natural gas-fired boilers through the use of two combustion techniques from KVB: exhaust gas recirculation and secondary combustion. These reductions were achieved without degradation of plant operation, efficiency or safety. Eight oil-fired boilers are also being converted to use the two techniques. The company will be in compliance with the Los Angeles County air pollution standards long before the 1975 deadline.

Construction of the Scattergood Steam Plant Unit 3 by the Los Angeles City Department of Water and Power (86018) was allowed to proceed solely on the basis of the low NO_x combustion techniques devised by KVB. The department had spent $6.5 million on construction and signed contracts totaling $24 million for equipment when a construction permit was denied on the basis of anticipated NO_x emissions of about 1,600 pounds per hour. After losing an appeal to a state court, the department was granted the permit when it agreed to operating changes that would ensure the plant's compliance with the new Los Angeles County air pollution standard limiting NO_x emissions to 140 pounds per hour. This plant is the first to be constructed under the new law, and department officials did not believe they could meet the 140-pound limit prior to the work done by KVB. The additional pollution control equipment will cost $2 million, as compared to the total plant cost of $68 million. Scattergood Unit 3 is scheduled to start producing almost 10 percent of Los Angeles' electricity in 1974. Most of the department's other 17 boilers are being converted to use the same techniques before the 1975 deadline.

The Public Service Company of New Mexico in Albuquerque (86013) has experimented with the techniques designed for the company by KVB. NO_x was reduced by more than 50 percent, and efficiency was increased in the trial plant. The techniques will probably be used in the company's plants in order to meet the New Mexico air pollution standards which will take effect in 1974.

Consolidated Edison Company of New York, Incorporated (86011) contracted with KVB to provide test supervision, analysis, and personnel training for the company's program to reduce NO_x emissions from its fossil-fueled steam and gas turbine plants. The company is testing KVB's combustion techniques in two medium-sized boilers, and the results appear to be favorable.

The Houston Lighting and Power Company in Texas (86012) has initiated a program to convert all 26 of its gas-fired boilers to use the secondary combustion technique designed for the company by KVB. Test programs on the Houston units have achieved NO_x reductions between 40 and 70 percent,

with no increase in operating costs. Houston Lighting and Power will receive the first innovative air recirculation boiler designed by a major boiler manufacturer (86014) in conjunction with KVB. The boiler design represents significant advances in NO_x reduction and increased efficiency for commercially available equipment.

The Gas Turbine Products Division of the General Electric Company in Schenectady, New York (86015) is conducting experiments with the techniques devised for its ground power turbines by KVB. The division is considering potential product design modifications which will reduce NO_x emissions by more than 50 percent.

The Babcock and Wilcox Company in Barberton, Ohio (86016) obtained the CEC program from Lewis Research Center about two years ago. The company uses CEC regularly in design studies for fossil-fired boiler modifications to reduce NO_x emissions and for sulfur recovery processes for several sulfur dioxide cleanup systems that are being developed for power plant exhaust gases. Babcock and Wilcox engineers analyze the operating trends for different hardware configurations with CEC so that guidelines leading to experimental design improvements are established.

The Phillips Petroleum Company in Bartlesville, Oklahoma (93825) has been using CEC since company scientists heard it described at the Lewis Research Center's High Temperature Research Conference. Phillips modified the Lewis program for use in its computers, and chemical equilibrium composition tables were then generated with the program for use in all of the company's combustion investigations. Typical combustion analyses using these data include: the combustion equilibria in internal gas combustion engines to aid in efforts to reduce NO_x and carbon monoxide emissions; pollutants from incinerators, when different materials are being incinerated; and the pollutants from burning waste gases with high concentrations of ammonia. A company spokesman estimated that it would have taken at least three man-years of work for Phillips to develop a program similar to CEC.

The Teledyne Continental Motors Division of Teledyne, Incorporated, in Mobile, Alabama (93826) plans to use CEC in its redesign of small aircraft engines to reduce NO_x and carbon monoxide emissions to comply with 1979 federal standards. Some of the Teledyne engineers had previously used CEC while working for a major aerospace contractor. Teledyne obtained the CEC program from Lewis to develop a combustion simulator that will be used to analyze the turbochargers on company aircraft engines. The analytical results will then be used to develop new turbocharger designs that will minimize NO_x and carbon monoxide emissions.

Control Numbers

Tech Brief Numbers:	68-10025, 68-10374, 68-10375, 68-10376, 68-10377
NASA Centers:	Lewis Research Center, Lyndon B. Johnson Space Center
TRIS Case Numbers:	86009, 86010, 86011, 86012, 86013, 86014, 86015, 86016, 86018, 93825, 93826
TEF Number:	463
Date of Latest Information Used:	February 7, 1973

FUEL VAPORIZATION MODEL TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Since the mid-1950's, the Lewis Research Center has developed several analytic methods to investigate rocket engine combustion processes in order to improve combustion efficiency and rocket performance. One of the methods, a propellant vaporization model, was described in a 1960 NASA Technical Report (NASA TR R-67). This model has provided NASA in-house and contractor personnel with the basis for performing improved analyses of heterogeneous combustion processes.

The Lewis vaporization model was designed to provide local vaporization rates, mixture ratios, and combustion conditions for numerous combinations of propellants, engine design parameters and operating parameters. This permits the nonhomogeneous conditions in a combustor to be modeled locally. The heat and mass transfers that occur between introducing a fuel and final combustion are included in the model. A technique for using the calculated results in the design of rocket combustors is also described in the report. Experimental results at Lewis exhibit good agreement with the model predictions.

The Dynamic Science Division of Marshall Industries, under contract to Lewis, subsequently improved the model and prepared a corresponding computer program. This research eliminated the need for several assumptions that were used in the original model. NASA has also supported the development of computer programs that complement the vaporization model by analyzing the actual combustion kinetics and the chemical composition of exhaust gases (see Technology Transfer Example Summary "Computer Programs to Analyze Combustion").

In 1970 a group of aerospace combustion experts, including those who had conducted the vaporization model research at Dynamic Science, formed a new company, KVB Engineering, Incorporated, in Tustin, California (87029). The new company has rapidly become a major combustion consulting firm for the electric utilities. The improved model is an integral part of the combustion analyses that KVB performs for electric power plant fossil-fired boilers. The analytic results are used to prescribe alterations in the hardware and operation of boilers. These alterations have reduced the formation of nitrogen oxides (NO_x) between 40 and 70 percent. The reduction is achieved at minimal cost without degrading the safety, efficiency, or operating costs for the boilers. No presently available alternative approach to solving the NO_x emission problem for stationary power plants appears to be comparable in cost or effectiveness to the KVB methods. Approximately 50 boilers belonging to 8 utilities have been adjusted in this manner to comply with emission standards set by law.

The vaporization model is crucial to the analysis of coal- and oil-fired boilers. KVB experts recently improved their analytic tools by coupling the vaporization program with a NASA contractor-developed chemical kinetics program to facilitate computer calculations. KVB has completed a successful preliminary test program on coal-fired boilers for the Arizona Public Service Company in Phoenix (87030). Minor adjustments were made in two boilers at the company's Four Corners Power Plant near Farmington, New Mexico for a three-week period, and a significant reduction in NO_x emissions was obtained. This was one of the first applications for the KVB techniques on coal-fired units. Arizona Public Service is currently considering a KVB proposal to conduct a more extensive study leading to permanent hardware and operation alterations in its coal-fired boilers.

Control Numbers

Tech Brief Number: None
NASA Center: Lewis Research Center
TRIS Case Numbers: 87029, 87030
TEF Number: 464
Date of Latest Information Used: February 9, 1973

COAL DESULFURIZATION PROCESS
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

TRW, Incorporated, under contract to the Lyndon B. Johnson Space Center, conducted an extensive test program for the Lunar Module rocket engines. The company constructed an integrated test facility for this purpose at its San Juan Capistrano Test Site, about 75 miles south of Los Angeles. The facility includes test stands and equipment, fabrication and maintenance shops, computerized monitoring and control equipment, a complete chemical laboratory, and a wide range of instruments. TRW invested about $2 million in the facility to support its space program contract work.

TRW Systems in Redondo Beach, California (96530) is using the San Juan test facility to develop an economic coal desulfurization process that may eliminate sulfur dioxide pollution problems associated with burning high sulfur coal from the eastern United States. The process, which was invented by TRW, uses an aqueous ferric solution to dissolve up to 80 percent of the sulfur in the coal. Since 1971, the company has received more than $500,000 from the Environmental Protection Agency (EPA) to test and evaluate the new process. EPA is also funding the construction of a half-ton per hour pilot plant at the San Juan site. The test facilities required only minor modifications for their new application. Subsequent commercial applications for the process are already being investigated by TRW, coal companies and electric utilities.

Control Numbers

Tech Brief Number: None
NASA Center: Lyndon B. Johnson Space Center
TRIS Case Number: 96530
TEF Number: 488
Date of Latest Information Used: January 31, 1974

PRECEDING PAGE BLANK NOT FILMED

APPLICATIONS OF RELIABILITY AND QUALITY ASSURANCE IN THE OFFSHORE PETROLEUM INDUSTRY TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The United States Geological Survey (USGS) is charged with regulating the offshore oil industry which is operating more than 1,800 drilling and production platforms on the Outer Continental Shelf (OCS). An increasing number of equipment failures has created a major public reaction to the resulting pollution and a demand for stricter regulations. In addition, the cost of OCS well blowouts to petroleum companies was estimated in Senate Interior Committee hearings to be $200 million.

In 1971, USGS contracted with NASA to pay the direct expenses for a group of five reliability and quality assurance experts from the Marshall Space Flight Center to study equipment and procedures used in the offshore oil and gas industry. The NASA study team analyzed the feasibility of applying advanced systems engineering techniques to increase the reliability of safety and antipollution equipment on offshore drilling and production platforms. The study report described appropriate quality control, failure mode effects analysis, and hazard analysis techniques based on previous space program applications. The report included a number of recommendations for improving safety and avoiding accidental pollution during offshore operations. Tech Brief 72-10588 announced the NASA study report; the principal means of dissemination, however, has been through USGS which distributed more than 4,000 copies of the report to the offshore oil industry and other interested groups around the world.

Industry and government reaction to the report has been very positive, and it is the basis for a dramatic change in offshore oil and gas production. A joint effort between the Survey and the American Petroleum Institute (API) was initiated in 1972 to develop procedures for implementing the NASA recommendations in specific applications. USGS will announce new regulations based on these procedures as they are developed. For example, the API report by the Committee on Subsurface Safety Valves has been reviewed and will soon be published. An OCS Order based on this report will be issued by USGS early in 1974, a little over 12 months after the NASA team study was completed. Other API committees are working on surface safety systems, research and development needs, personnel training and pipeline corrosion. Most of the Survey's activities are done by the Conservation Division's Gulf of Mexico OCS Operations Office in New Orleans, Louisiana (93831).

The Survey and several oil companies have contracted with former NASA contractors to conduct systems analysis (i.e., hazards analysis in aerospace terminology) for offshore facilities and to develop employee training programs. The General Electric Company's Apollo and Ground Systems group at the Lyndon B. Johnson Space Center (96528) is selling consulting services to the offshore industry and USGS based on the reliability and quality assurance technology that GE developed under NASA contracts. The GE consultants have conducted systems analyses, developed training programs, and identified new operating procedures and equipment.

Exxon Company in Houston, Texas (93829) is one of the largest offshore oil and gas companies in the world. In response to the recommendations in the NASA team report, Exxon retained GE reliability consultants to conduct systems analyses for several production facilities. Equipment and procedural modifications were identified; Exxon has implemented most of these changes through the addition of redundant safety equipment or improved identification of control switches to reduce human error. Exxon is also conducting design analyses to improve reliability in more fundamental ways.

The Offshore Operators Committee, with offices in New Orleans, Louisiana (93830), is made up of representatives from oil and gas companies that operate on the Outer Continental Shelf. Based on recommendations in the NASA team report, two important new mechanisms are being developed by the Committee to improve safety and reduce pollution for offshore equipment: a computerized failure reporting system and new engineering documentation requirements for equipment manufacturers. A Committee report that describes the proposed failure reporting system is being reviewed by USGS. Either the Committee or USGS will probably institute and operate this system within the next few years for the offshore oil and gas companies. Both the reporting system and the documentation requirements could become significant mechanisms for improving the reliability of offshore equipment by providing performance feedback to equipment designers.

Control Numbers

Tech Brief Number: 72-10588
NASA Centers: Marshall Space Flight Center, Lyndon B. Johnson Space Center
TRIS Case Numbers: 93829, 93830, 93831, 96528
TEF Number: 484
Date of Latest Information Used: December 1, 1973

REFERENCES

PRECEDING PAGE BLANK NOT FILMED

REFERENCES

American Chemical Society, Committee on Chemistry and Public Affairs, Subcommittee on Environmental Improvement. *Cleaning Our Environment: the Chemical Basis for Action*. Washington, D. C.: 1969.

__________, *A Supplement to–Cleaning Our Environment; the Chemical Basis for Action*. Washington, D. C.: 1971.

Barringer, Anthony R. "Correlation Spectrometry Applied to Earth Resources," in *Proceedings of the Princeton University Conference on Aerospace Methods for Revealing and Evaluating Earth's Resources*. Princeton, New Jersey: The Princeton University Conference, June 1970.

__________, and J. H. Davies. *Investigations in Correlation Spectroscopy and Interferometry for the Remote Monitoring of Air Pollution*. Paper presented at the Joint Conference on Sensing of Environmental Pollutants, Palo Alto, California, November 1971.

Becker, David, Peter Shipma, and John Stockham. *Technology Utilization Survey of Air Pollution Monitoring Instrumentation*. Falls Church, Virginia: Computer Sciences Corporation, February 1972. (Draft Material.)

Bortner, M. H. Manager, Atmospheric Chemistry Programs Section, Space Sciences Laboratory, General Electric Company, Philadelphia, Pennsylvania. Telephone interview on February 5, 1974.

__________, *et al. Analysis of the Feasibility of an Experiment to Measure Carbon Monoxide in the Atmosphere*. NASA CR-2303. Washington, D. C.: National Aeronautics and Space Administration, October 1973.

__________, *et al. Development of a Breadboard Model Correlation Interferometer for the Carbon Monoxide Pollution Experiments*. NASA CR-112212. Philadelphia, Pennsylvania: General Electric, March 1973.

Chrysler Corporation, Huntsville Division. "Application of Aerospace Technology to General Industry." Huntsville, Alabama: [1972]. (Mimeographed.)

__________. "Vehicle Exhaust Analyzer Model 1A – Specification." Revision B. [Huntsville, Alabama]: 1971. (Mimeographed.)

Copeland, G. E., *et al.* "Remote Detection of Aerosol Pollution by ERTS," in *Symposium on Significant Results Obtained From the Earth Resources Technology Satellite-1*. NASA SP-327. Washington, D. C.: National Aeronautics and Space Administration, 1973.

Council on Environmental Quality. *Environmental Quality, The Third Annual Report of the Council on Environmental Quality*. Washington, D. C.: Government Printing Office, August 1972.

Graham, Fred P. "Justices Give Courts Pollution Power," *New York Times*, April 25, 1972.

Hodgeson, J. A., W. A. McClenny, and P. L. Hanst. "Air Pollution Monitoring by Advanced Spectroscopic Techniques," *Science*, CLXXXII (October 19, 1973), 248-257.

Hollowell, Craig D., and Ralph D. McLaughlin. "Instrumentation for Air Pollution Monitoring," *Environmental Science and Technology*, VII (November 1973), 1011-1017.

Hrubesh, L. W. "Feasibility Study of a Gunn-Diode Cavity Spectrometer as a Formaldehyde Monitor: Quarterly Report March-June, 1973." Livermore, California: Lawrence Livermore Laboratory, 1973. (Mimeographed.)

Lawrence, James D., Jr., and Lloyd S. Keafer, Jr. "Remote Sensing of the Environment," in *Proceedings of the Interagency Conference on the Environment*. CONF 721002. Washington, D. C.: Atomic Energy Commission, [1973].

Lind, Aules O. Professor of Geography, University of Vermont, Burlington, Vermont. Telephone interview on January 29, 1974.

__________, E. Bennette Henson, and James Pelton. "Environmental Study of ERTS-1 Imagery: Lake Champlain and Vermont," in *Symposium on Significant Results Obtained From the Earth Resources Technology Satellite-1*. NASA SP-327. Washington, D. C.: National Aeronautics and Space Administration, 1973.

McGraw-Hill Publications Company, Economics Department. *The Sixth Annual McGraw-Hill Survey of Pollution Control Expenditures.* New York: 1973.

McMillin, L. M., *et al. Satellite Infrared Soundings From NOAA Spacecraft.* NOAA TR NESS 65. Washington, D. C.: U. S. Department of Commerce, September 1973.

Maugh, Thomas. "Pollution Instrumentation: A Trend Toward Physical Methods," *Science*, CLXXVII (August 25, 1972), 31.

Morgan, G., G. Ozolins, and W. Sayers. "Monitoring Environmental Quality," in *Proceedings of the Interagency Conference on the Environment.* CONF 721002. Washington, D. C.: Atomic Energy Commission, 1973.

National Aeronautics and Space Administration. ERTS-1 Photo no. 72-HC-711, August 16, 1972.

Predicasts, Incorporated. *Market Opportunities in Environmental Control and Safety.* Cleveland, Ohio: May 1973.

Spohn, Clifford A. "The Present and Future Satellite System," in *Seminar on Operational Remote Sensing.* [Falls Church, Virginia]: American Society of Photogrammetry, 1972.

Staelin, D. H., *et al.* "Microwave Spectrometer on the Nimbus 5 Satellite: Meteorological and Geophysical Data," *Science*, CLXXXII (December 28, 1973), 1339-1341.

Talley, Wilson K. "The Federal Government, the National Laboratories, and the Environment," in *Proceedings of the Interagency Conference on the Environment.* CONF 721002. Washington, D. C.: Atomic Energy Commission, 1973.

Teich, Albert H., *et al. Environmental Research Laboratories in the Federal Government – An Inventory.* Vol. II. Syracuse, New York: Syracuse University Research Corporation, September 1971.

U. S. Congress, Senate, Committee on Aeronautical and Space Sciences. *NASA Authorization for Fiscal Year 1974; Hearings Before the Committee February 28; March 6, 7, and 9, 1973.* (93rd Congress, 1st Session.) Washington, D. C.: Government Printing Office, 1973.

U. S. Environmental Protection Agency. *The Challenge of the Environment: A Primer on EPA's Statutory Authority.* Washington, D. C.: July 1972.

Wezernak, C. T., and N. Roller. "Monitoring Ocean Dumping with ERTS-1 Data," in *Symposium on Significant Results Obtained From the Earth Resources Technology Satellite-1.* NASA SP-327. Washington, D. C.: National Aeronautics and Space Administration, 1973.

White, William. Contract Monitor, NASA Langley Research Center, Hampton, Virginia. Telephone interview on January 2, 1974.

Yates, Harold W. "Remote Sensing From Satellites," in *Remote Sensing of the Troposphere*, ed. V. E. Derr. Washington, D. C.: U. S. Department of Commerce, National Oceanic and Atmospheric Administration, 1972.